NUCLEONICS

TECHNIQUES AND APPLICATIONS OF NUCLEAR SCIENCE AND ENGINEERING

December, 1951

Exposing plants to cobalt-60 gamma rays for photosynthesis studies

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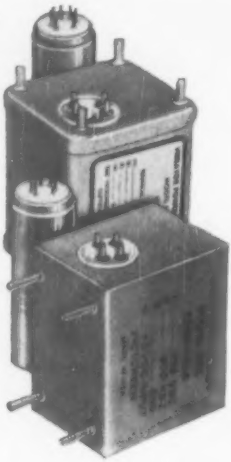

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NUCLEONICS

DECEMBER · 1951

THE COVER shows plants being exposed to simulated sunlight to enable them to carry on photosynthesis. The heart of the equipment is the lead pig at left which houses two curies of cobalt-60. Funnel-shaped plug is removed from the shield by remote-control lever to expose plants to gamma rays in these experiments at Brookhaven National Laboratory.

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Fission Products and Research Reactors

The atomic energy program in this country is run for the government by contractors. Because of secrecy restrictions, the initiative in the negotiation of major contracts has been largely with the Atomic Energy Commission. This has had the tendency to keep those groups not on the "in" from grasping the full significance of what the impact of atomic energy might be on their own interests.

This state of affairs is borne out in connection with two announcements made in California last month. The first was from the Stanford Research Institute which completed its study of industrial uses of fission products; the second was from North American Aviation, Inc., which described its design of a low-power research reactor. Both projects were carried out under contract with AEC.

1. Stanford. The most important conclusions reached in this study (based on discussions with 60 companies said to be representative of major U. S. industry) are that there are many potential uses of fission products and that the size of the market depends upon their price. If they can be made to be sold for $1 to $2 a curie, there may be an assured market of around a million curies per year. If, instead, the price is $50 to $100 per curie, the potential market might be of the order of tens of thousands of curies per year.

Thus, there are two opportunities here—in the use of fission products and in their sale. In the case of the latter, once certain technological problems are licked, there may be the chance for someone to build a fission-product processing plant at an optimistic cost of $10-million and sell fission products to all comers.

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But the biggest bottleneck in the development of any market is the need for education—of the general public and of industry. Informing and educating the public is necessary so that products made through use of radiation will evoke consumer confidence. Enlightenment of industry is obviously necessary so that it will be able to investigate possible applications.

In its survey, Stanford found that a considerable number of companies were relatively uninformed as to radiation safety problems. This lack of knowledge usually resulted in an "unfounded fear of radiation."

This is particularly surprising when we consider the excellent sources of information available. However, recognizing the psychological barriers which exist to working with a new force such as radiation, the editors of NUCLEONICS plan to take a hand in this matter.

We here announce a special service. We will assist any company, university, or hospital in getting started in this field by advising on availability and sources of information. Inquiries should be addressed to the Editor, NUCLEONICS, 330 W. 42d St., New York 18, N. Y.

2. North American Aviation. The second of two announcements referred to earlier was the first public description of the 160-kw research reactor designed by North American. This is a unit designed for AEC but presumably to be built by or for a non-AEC organization.

In its 1951 budget, AEC set aside $1.4-million for a "research reactor, location undetermined." At that time, it was considering the possibility of one of three locations—Washington, D. C., Ames, Iowa, or the southern California region.

Although the design of this reactor was completed in October, 1949, no formal proposals have yet been submitted to the AEC. Either no group wants AEC to build a reactor for it or else none have the money to pay for such a reactor themselves.

But here is an excellent opportunity for a group of universities or hospitals or companies, or a combination of all three, to look to the future by building the newest of major research tools.

Thus, in both the utilization of fission products and in the building of research reactors, the extent to which groups now "on the outside" participate in this field depends almost entirely upon how much initiative they show. —*J.D.L.*

SPECIAL ANNOUNCEMENT!

Effective with the January, 1952, issue, the physical dimensions of NUCLEONICS will be increased from the present 5½ x 8 in. to 8¼ x 11¼ in. At the same time, the editorial content will be materially increased. Complete details on what's behind this expansion will be given in the January issue.—*The Editors*

How the NEW G-E PROBE detects thermal Neutrons and Alpha, Beta, Gamma Radiation

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Tripartite Instrumentation Conference—1951

Representatives from American, Canadian, and British atomic-energy projects met at Harwell, England, on April 30, 1951, for a week's conference on new developments in instrument circuitry and components. Prepared at NUCLEONICS' request, this report describes highlights of the meetings

By DENIS TAYLOR

Atomic Energy Research Establishment
Harwell, England

THE PURPOSE of the Tripartite Instrumentation Conference held in England in April, 1951, was to discuss the components, circuits, and instruments in current use on atomic-energy projects in the United States, Canada, and Great Britain, and to consider those planned for future use.

Discussions centered, generally, on counting-rate meters, low-background counting apparatus, new techniques for scaling, millimicrosecond techniques, automatic counting apparatus, pulse-amplitude analyzers, and lightweight radiation-monitoring instruments.

Counting-Rate Meters

The accuracy of counting-rate meters, unlike scalers, is limited by the stability of the circuit components used, e.g., resistors, capacitors, and tubes, and by the voltages. The resulting doubts about over-all stability and linearity of these meters has tended to limit their use to applications in which only a modest accuracy is required. Errors can, however, be considerably reduced by careful design. It was reported at the conference that instruments are now available that can provide an over-all accuracy of better than $\pm 1\%$, and that counting-rate meters are now being used for purposes for which scalers have been used in the past.

The main problems in the design of a linear counting-rate meter are to ensure that the charge per pulse fed to the tank capacitor is constant, to obtain a tank circuit time constant of adequate length without introducing errors due to unwanted leakage, and to minimize the effects of tube variations.

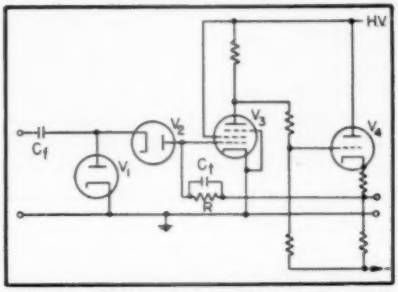

FIG. 1. Basic circuit of counting-rate meter

One of the circuits (*1*) described is shown in Fig. 1. The problem of feeding a constant charge per pulse into the tank capacitor is simplified if the potential of the point at which this is done is maintained nearly constant, irrespective of the charge already present on the capacitor. This is achieved in the circuit shown by using the tank capacitor and its leak resistor to form the feedback element of a feedback d-c amplifier.

Referring now to Fig. 1, it will be noted that each time a square pulse of large amplitude V is fed through C_f to the diodes V_1 and V_2, a charge VC_f is developed across C_t. However, any

potential change at the grid of V_1 is strongly opposed by a much larger change in the opposite direction at the cathode of V_2. As a result, most of the change of potential VC_t/C_t, which occurs across C_t as a result of the arrival of a pulse, appears at the cathode of V_2, the grid potential of V_1 remaining almost constant. The cathode potential of V_2 is thus a linear function of the counting rate.

Another problem which was discussed was the design of meters for measuring low counting rates. If the integrating time of such a circuit is made small, because an approximate result is wanted in a short time, the fluctuations of the rate-meter output include not only sharp peaks caused by the arrival of a charge on the tank capacitor for each pulse counted but also statistical fluctuations due to the random nature of the input pulses.

The former type of fluctuation increases the error and a modified circuit was suggested at the conference to decrease this effect. Fig 2 shows the modified circuit. The integrating capacitor is indicated between the anode and grid of V_2, and an additional circuit C′R′ is indicated in the grid circuit of V_2. It can be shown that the behavior of this circuit is the same as that of a capacitor C across which is connected a resistor in series with an inductance. The circuit responds to a sudden addition of charge in C by a damped oscillation of current in R_1.

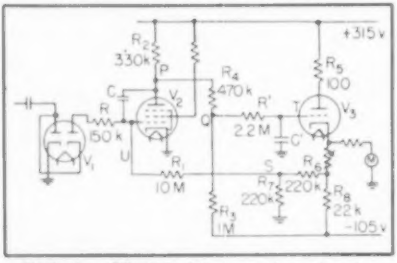

FIG. 2. Modified integrating circuit

Suitable proportioning of CR, C′R′, and the attenuation between P and S, produces a state of critical damping. Under these conditions, the effect of the individual additions of charge to C has a much smaller effect on the output, while the standard deviation due to random input pulses is unaffected. The rate of response of the output to a change of mean input pulse rate is at first somewhat slower, but eventually the final reading is approached in a rather shorter time than with the circuit that is not modified.

Low-Background Counting Apparatus

The conference also discussed the application of scintillation methods to low-background alpha counting.

The American and Canadian equipment discussed was similar to that described in the literature by Baurmash and Dietrich (*2*).

The British equipment uses an E.M.I. photomultiplier tube in place of the RCA tube, and a more elaborate optical system is employed. The latter (*3*) comprises an internally silvered ellipsoidal shell concentrating the light from the phosphor screen, which is placed at one focal plane, onto the cathode of the photomultiplier, which is placed at the second focal plane.

All the instruments give about the same performance. A typical figure for background counting rate for a standard sample area of 10 cm^2 and counting efficiency of 35% is about 2 counts per hour.

There was some difference of opinion about the best technique for low-background alpha counting. The Americans and Canadians were generally in favor of using scintillation methods, but the British seemed to prefer gas counters operating in the proportional region when backgrounds of the order of 1 count per hour were required. One design of such a gas counter, due to Sharpe and Bennett (*4*), is shown in

Fig. 3. The counter consists of a mild steel block with a hemispherical cavity 30 mm in diameter. The anode is a 3-mm loop of 0.002-in. tungsten wire, the center of the loop being mounted approximately 13 mm above the base of the hemisphere. A low-background head amplifier is mounted on top of the counter so that the first tube can be wired directly onto the anode. The complete counter assembly is a shallow cylindrical can 6 in. in diameter and ¾ in. deep, the counter and amplifier being mounted in the lid of the can.

The gas counter shown in Fig. 3 has been adapted for automatic counting, and facilities are provided so that the unknown source, a standard source, and an empty source holder are inserted into the counter in turn. To move the source holders into the counter proper in turn, the sources are held on a small turntable 3¾ in. in diameter. The turntable is driven by a small pinion that is coupled through a gastight gland to a motor mounted underneath the counter assembly. This design prevents any ingress of air into the counting volume as the sample is changed, thereby obviating the need for any preflushing and enabling the unit to be operated without attention. The gas enters at the top of the counter and must flow over the turntable surface before it can pass out the exit pipe mounted below the turntable. It is necessary to allow about 5 min to flush the unit only at the beginning of an experiment. A source can be changed in about 20 sec.

A small control unit provides for automatic counting of the unknown sample for one hour, the background (empty holder) for one hour, and the standard source (< 100 cpm) for a quarter of an hour, the activities being recorded on a three-pen event recorder and totalized on three registers. The event recorder provides a check on whether any bursts of interference have occurred.

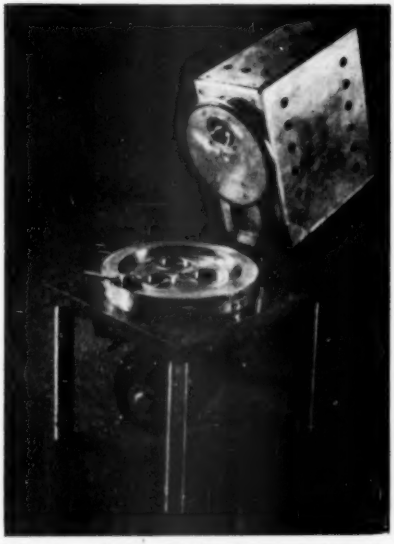

FIG. 3. Three-position flow counter with head amplifier for automatic counting

There was some discussion at the conference about the production of low-background amplifiers for use with low-background counting equipment. It was pointed out that, with careful design, spurious pulses need not cause more than about 1 count per 24 hours. Spurious pulses fall into two classes: (*a*) those produced internally in the amplifier by the components and tubes, and (*b*) those produced externally which find their way into the amplifier either along the input lead or by direct radiative pick-up.

Internally generated pulses can be reduced to a minimum by using good paper capacitors for all decoupling and bias capacitors, by using good paper or mica capacitors for all interstage capacitors, and by choosing for the first tube in the head amplifier one with reasonably large grid and cathode spacing, consistent, of course, with good characteristics in other directions. Tests were reported on four tubes: the American 6AK5, the British EF91 (a

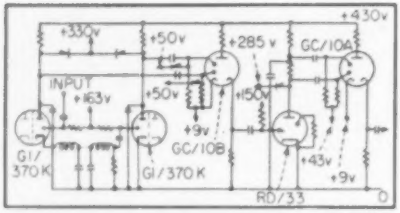

FIG. 4. Scaling circuit using cold-cathode tubes

miniature high-slope pentode), the British EF54 (a nonminiature high-slope pentode), and the British ME1400 (a nonminiature medium-slope pentode) selected for low grid current. The ME1400 was unquestionably the best tube, while the 6AK5 gave the poorest performance. It is now believed that the internally generated spurious pulses are produced by small pieces of foreign matter that become attached to the electrode structure and produce intermittent leakage paths between the grid and cathode of the tube.

New Techniques for Scaling

The majority of the scalers in use in the three countries employ a double triode for each scale-of-two and four double triodes and usually four diodes per decade.

Considerable interest is being shown in the use of cold-cathode trigger tubes in such instruments to avoid the high power dissipation necessary with the conventional thermionic-tube scaler and to give increased reliability. Reference was made to the scalers used in the Harwell pulse analyzers (*5*). It was noted that of the 200 cold-cathode tubes used in these instruments only one needed replacement over the period of a little more than a year. The use of a scale-of-ten in one envelope was discussed, and reference was made to the several cold-cathode tubes of this type which are now available, notably the tubes manufactured by Remington Rand, Ltd. (*6*); Ericsson, Ltd. GC/10A (*7*); and Standard Telephone and Cables, Ltd. G10/240E (*8*).

The Ericsson tube consists of a central anode surrounded by 30 wires which form three interlaced systems of ten wires each. These systems are termed the cathode, first guide, and second guide systems, respectively. The tenth cathode wire is brought out separately and termed the output cathode. The guides normally operate at a higher potential than the cathodes, so that the discharge passes between the anode and one of the cathode wires. If the first guide potential is reduced below that of the cathodes for a short period of time, the beam transfers to the first guide wire adjacent to the struck cathode. If then, as the first guide is released to its normal potential, the second guide potential is reduced for a short period, the beam transfers to the second guide. Finally, when this guide is released to its normal potential, the beam transfers to the next cathode. Thus, two successive negative pulses, each of the required duration, are needed to cause the beam to transfer from one cathode to the next. The electrode systems are arranged so that the glow discharge takes place at the end of the tube; hence, the tube is self-indicating.

Much use is being made of the Ericsson tube in Great Britain. Figure 4 shows the circuit of a British scaler which uses these tubes. Two trigger tubes are used in the input circuit, the first tube being triggered by the input pulse and the second by the delayed pulse from the first. A single tube is used for coupling successive scales-of-ten.

The present Ericsson tube GC/10A has a resolving time of about a millisecond, but faster tubes are available. They have resolving times of about 50 microseconds,* which makes them fast

* The tubes made by Standard Telephone and Cables, Ltd., and Remington Rand, Ltd., have resolving times of this order.

enough for a large proportion of the nuclear measurement work normally encountered.

The policy in Britain has been to replace many of the conventional scalers with tubes of this new type.

Millimicrosecond Techniques

One of the most interesting discussions at the conference was on the subject of millimicrosecond techniques. *Messrs. N. F. Moody and G. Cowper* (National Research Council, Canada) gave details of a number of circuits that use Mullard EFP60 secondary emission pentode tubes. These included chain amplifiers having gains of 4 to 5 per stage with a frequency response extending to 50 Mc/sec, trigger circuits based on the secondary emission pentode's negative resistance with a 5×10^{-9} sec time of rise, and pulse-amplitude discriminator circuits with a resolving time of the same order. They also gave the circuit details of a time-sorter that uses a number of high-speed coincidence units in cascade and described how the complete instrument can be employed to investigate short-life phenomena.

P. R. Bell (Oak Ridge National Laboratory) described his delayed coincidence scintillation spectrometer and gave details of some of the measurements he had made with it, including the measurement of the half-life of $_{76}Os^{186}$ as 8×10^{-10} sec.

There was much interest shown in a fast scaler (*9*) not because of its performance characteristics, but because of the circuit technique used. The basic circuit is shown in Fig. 5. It is essentially a step-charge device, the capacitor C being given a known increase of charge for each input pulse received. To avoid errors due to loss of charge, the voltage across this capacitor is stabilized by a series of tubes at any one of four known potentials. In the rest condition, capacitor C is charged via the 2.2-megohm resistor

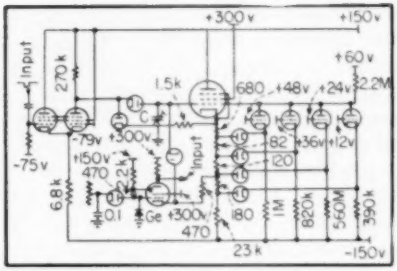

FIG. 5. Fast scaling circuit

to a potential of +60 volts. Each input pulse causes a reduction of potential of C by 12 volts, this reduction of potential operating the diode switches through the cathode follower. As each diode in turn is cut off, the triode attached to it becomes fully operative and clamps the capacitor to the triode grid potential. In this manner, the capacitor potential may be held indefinitely. After the fifth pulse has been applied to the condenser, the EFP60 trigger circuit operates and causes the condenser to flash back rapidly to its original potential.

Another matter discussed at the conference was the speed of operation of the photomultiplier tubes used in scintillation counters. Results were reported on experiments with bursts of X-rays using a crystal of stilbene and a photomultiplier tube as the detector components. With the nonfocusing type of photomultiplier tube, the delay time was of the order of 3×10^{-8} sec and the spread in this delay was about 3×10^{-8} sec. With the self-focusing type of photomultiplier tube, the delay was 1×10^{-8} sec and the spread was less than 5×10^{-9} sec. These results indicate the advantage to be gained by using the self-focusing type for measuring short time intervals.

Automatic Apparatus

Automatic counting apparatus (*10*) is now being used on a large scale. In

some cases, the mechanical portion of the apparatus is pneumatically operated. Quite apart, however, from these aids to facilitate routine assays, automatic apparatus is now being employed to meet more specialized requirements. A good example of this is the apparatus shown in Fig. 6 where continuous monitoring of the liquid activity from an ion-exchange column is required in order to route the liquid into the correct bottle, one bottle being used for each element.

A typical curve of activity against time consists of a series of peaks and troughs, and it is therefore necessary to change a bottle either when the activity drops below a predetermined level, or when the activity-versus-time curve reaches a minimum. In the apparatus shown, the liquid is passed through a flow-through Geiger-Müller counter, the counter output being passed to a counting-rate meter of special design. This measures not only the counting rate but also the rate of change of counting rate so that the minimum of the curve can be registered.

Special precautions are taken automatically in this apparatus to ensure that no more than a certain quantity of liquid passes into any one bottle. This is necessary to avoid overflowing and involves the use of a photocell liquid meniscus detector.

Pulse-Amplitude Analyzers

Pulse-amplitude analyzers of many types are available. They are essential instruments in all nuclear physics laboratories. The majority of pulse analyzers so far constructed use biased discriminators. With this method, the conference noted, there was the inherent difficulty of preventing the lower discriminators from counting with a slowly rising input pulse.

Three methods have been used to overcome this difficulty. The first method (*5*) uses a sensitizing pulse in conjunction with a pulse-lengthening system. In the second method (*11*), a count is registered on the recovery of the discriminator, if this has not been cancelled by the previous recovery of a higher discriminator. In the third method (*12*), all channels count up to the maximum height of the pulse on receipt of the first pulse, but the channel which counts the biggest pulse then makes lower channels insensitive to the next pulse.

The second and third methods involve the use of wide-band amplifiers and fast discriminators. All methods involve careful manual voltage setting.

Reference was made at the conference to the new pulse-amplitude analyzers involving amplitude-to-time conversion. These are very attractive since accurate measurements of time are much easier to make than accurate measurements of voltage. A high-precision pulse analyzer of this type and capable of moderate speed was described by *G. G. Scarrott* (*13*). In this instrument, information is stored in a supersonic delay-line and is displayed on a cathode-ray tube. The accuracy of channel width and the linearity of response are both one part in a thousand. The number of channels and the storage capacity per channel of this instrument can be varied at will to give 60 channels of up to 10^6 pulses, 80 channels of up to 3×10^4 pulses, or 120 channels of up to 1,032 pulses. The maximum counting rate is 1,600 per second.

Lightweight Monitoring Instruments

The design of lightweight radiation-monitoring instruments involves many special problems, and some interesting designs were described at the conference by *H. D. LeVine* (AEC New York Operations Office), *F. R. Shonka* (Argonne National Laboratory) *P. R. Bell* (Oak Ridge National Laboratory), and *E. Franklin* (AERE, Harwell).

An ion-chamber instrument measur-

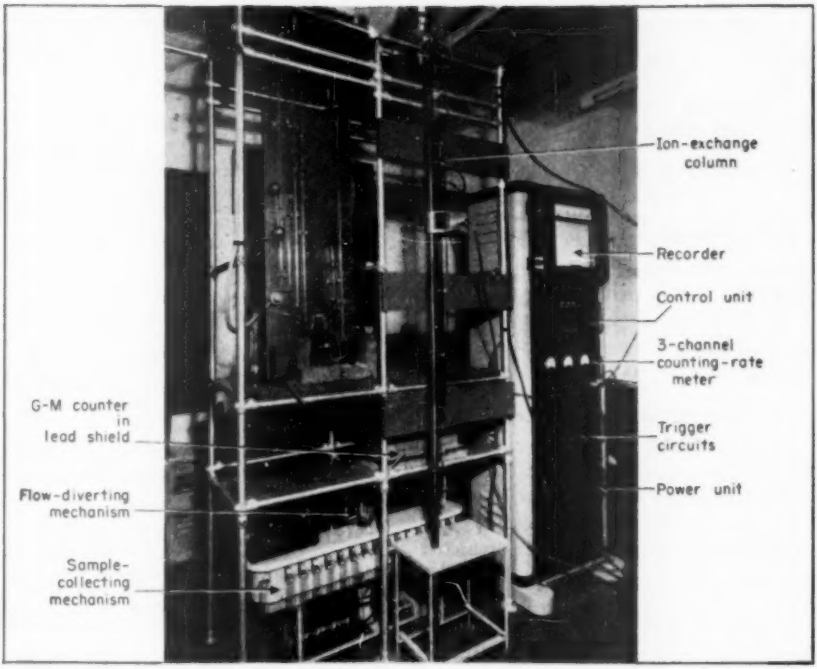

FIG. 6. Automatic radioactive liquid-sample separator

ing $4 \times 2 \times 1\frac{1}{2}$ in. was described by Bell. It operates by balancing grid current against ion current. The standing tube current in this instrument is 30 μa, and this is backed off by the meter spring. The scale is logarithmic and covers 0–500 r/hr. There was much discussion about this instrument.

The relative merits of using an ion chamber and a Geiger counter and the merits and demerits of using an electrometer-tube circuit or a quartz-fiber electrometer, or avoiding the use of an electrometer altogether and using the circuit of LeVine *et al.* (*14*) with a Geiger counter were also discussed. No general agreement was reached. It was noted that although much effort is being put into obtaining a logarithmic-scale instrument this is, in fact, not the ideal; the ideal would have a scale that widens with increasing reading. Accuracy in reading the higher dose-rates is, in general, more important than accuracy in reading low dose-rates. Further, it was noted that a calibration check at full or three-quarters-full scale was probably more satisfactory from the point of view of accuracy of high dose-rate readings than a zero-set control or the equivalent.

Many novel components (*15*) for lightweight instruments were reported. These included a clockwork-driven electric generator weighing about 2 lb to replace the batteries used in portable instruments, cold-cathode tubes in place of thermionic tubes, and a fluid-light type of tuning indicator designed to take the place of the meter in portable instruments. Quartz-fiber electrometer's movements of high sensitivity and sur-

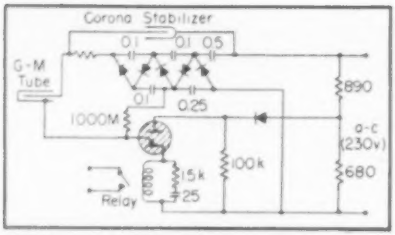

FIG. 7. G-M counter operated by a-c

prising robustness were described by Shonka.

It would seem that many portable instruments with new features will be finding their way into laboratories soon.

Line-operated G-M Counter

At the conclusion of the sessions, *E. H. Cooke-Yarborough* (AERE, Harwell) mentioned that there often was a need for a simple and cheap Geiger counter detector that could be operated on line voltage instead of batteries. His circuit is shown in Fig. 7. It will be noted that 230 volts a-c is applied first to a Cockcroft-Walton multiplier circuit and then to the Geiger counter. The cold-cathode tube triggered by the counter is also operated from the a-c supply. This simple circuit may be of value in industrial applications.

* * *

I am indebted to Messrs. C. D. Florida and W. R. Loosemore, the official secretaries of the Tripartite Conference, who have allowed me to use some information prepared for the official report, and also to the Director, AERE, for permission to publish this article.

BIBLIOGRAPHY

1. E. H. Cooke-Yarborough, E. W. Pulsford, *J. Inst. Elec. Engrs. (London)* **98,** Pt. II, 191 (Apr., 1951); same basic circuit also used in design of an accurate logarithmic counting-rate meter, *ibid.*, p. 196.
2. Leonard Baurmash, J. E. Dietrich, NUCLEONICS **9,** No. 3, 73 (1951)
3. R. B. Owen, E. A. Sayle, *J. Inst. Elec. Engrs. (London)* **98,** Pt. II, 245 (1951)
4. J. Sharpe, A. E. Bennett (private communication)
5. E. H. Cooke-Yarborough, J. Bradwell, C. D. Florida, G. A. Howells, *J. Inst. Elec. Engrs. (London)* **97,** Pt. III, 108 (1950)
6. J. J. Lamb, J. Brustman, *Electronics* **22,** No. 11, 92 (1949)
7. R. C. Bacon, J. R. Pollard, *Electronic Eng.* **22,** 173 (May, 1950)
8. G. H. Hough, D. S. Ridler, *Elec. Commun.* **27,** 214 (Sept., 1950)
9. F. H. Wells, *J. Sci. Instr.* (in press)
10. A. E. Bennett, *Electronic Eng.* **23,** 81 (Mar., 1951) (contains details of components used in British automatic counting apparatus)
11. N. F. Moody, W. D. Howell, W. J. Battell, R. H. Taplin, *Rev. Sci. Instr.* **22,** 551 (1951)
12. G. Vallidas, J. Thenard, *J. phys. radium* **11,** Pts. 8–9, 501 (1950)
13. G. W. Hutchinson, G. G. Scarrott, *Phil Mag.* **42,** 792 (1951)
14. H. D. LeVine, H. J. DiGiovanni, M. R. Coe, NUCLEONICS **6,** No. 6, 56 (1950)
15. Some of the components are described in papers in press, as follows: D. Taylor, W. Abson, "Electrical Instrument Design Conference," *J. Inst. Elec. Engrs. (London)* **98** (Dec., 1951); and E. Franklin, J. Hardwick, "Design of Portable Beta- and Gamma-Radiation Measuring Instruments," *J. Brit. Inst. Radio Engrs.* **11** (Oct., 1951)

CORRECTIONS . . .

The following corrections should be made in the article on "Photographic X- and Gamma-Ray Dosimetry" in the September, 1951 issue of NUCLEONICS:

Page 7, first column. Formula should read $I(E)dE = -C(E - E_0)dE$

Page 9, Fig. 4. Middle curve should be labeled 0.05 cm Pb

Page 11. First word should be 10,000 r

Page 13, Fig. 8. Title of second picture should be Dupont 510. In the fourth picture, unlabeled curve is 0.22 mm Pb, bottom curve should be 0.33 mm Pb

Page 16, Table 4. Filter used for 150-kv exciting potential should be 1.53 mm Sn + 4 mm Cu

Fatigue Effects in Scintillation Counters

The precision of quantitative results from high-rate counting with scintillators may be seriously affected by fatigue in the photomultiplier. Data on counting-rate stability for 5819 tubes are used here to define optimum operating conditions

By L. REIFFEL, C. A. STONE, and A. R. BRAUNER

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THE HIGH RESOLVING power and short recovery time of scintillation counters has made possible many applications involving megacycle pulse-counting rates. In particular, substantial counting rates often occur in measurements on short-half-life activities and in biological experiments with high-efficiency phosphors. Under such circumstances, where precise quantitative information is desired, it has been found that "fatigue effect" in the counting photomultiplier may seriously affect the results. This is true even at the remarkably low final dynode currents (< 1 μa) corresponding to zero-bias extrapolated counting rates of 10^6 cpm.

The so-called fatigue effect in photoemissive surfaces is a well known phenomenon, although comparatively little quantitative study has been made of it. Work that has been done in connection with photomultiplier tubes* has indicated, for the average photomultiplier dynode surface, very little decrease in the effective secondary-emission ratio at currents up to 5 μa, and completely negligible fatigue at currents under 1 μa. The fatigue at such direct currents is unimportant for total current measurements. However, use of a pulse-height selector with rapidly varying pulse-density distributions from a scintillator may result in very large changes in the observed counting rate even though changes in multiplier gain are quite small.

Counting-rate-stability tests were run on randomly selected members of a group of 55 RCA type 5819 photomultipliers, operated at 900 volts with a 1.25 in. diameter, 1.06 in. long NaI(Tl) phosphor and the 1.1- and 1.3-Mev Co^{60} gamma rays. Since these multipliers were not selected on the basis of high photocathode efficiency, the average resolution of the counters as energy spectrometers was quite poor. In the typical differential-pulse-height spectrum for these tubes shown in Fig. 1, neither the photopeaks nor the Compton peak are resolved.

Data were obtained on the counting-rate stability of the counter-discriminator-scaler system by setting up a 1.04-mc Co^{60} source at distances of 8 and 14 in. from the crystal and a 3.6-rutherford "sensing" source at a distance of 26 in. First a series of runs were made with only the weak sensing source to make certain the system was

* G. H. Dieke. A study of standard methods for spectrographic analysis, Report W-193, War Production Board, (May, 1945); R. W. Engstrom, *J. Optical Soc. Am.* **37**, 423 (1947).

stable for low rates. These preliminary runs were made in exactly the same fashion as the intensity runs to follow; i.e., the discriminator was set at an arbitrarily chosen pulse height with reference to the maximum Co^{60} pulse height, and the scaler started manually. At the end of a 30-sec interval, timed by a stop-watch, the scaler was stopped, the count recorded, the scaler and watch reset and finally started again for another 30-sec interval. The time required for two operators to record, reset, and restart was roughly 4 sec. Every fifth or sixth run an additional 10 sec were required to measure the anode current with a 3,000-megohm voltmeter across a 10-megohm by-passed resistor in series with the normal anode load of 5,000 ohms. To avoid grid-current effects, the cathode follower used to couple the pulse output to the discriminator was disconnected during these current measurements.

Typical results for rate stability with the sensing source alone are definitely constant within the statistical accuracy of $\pm 3\%$ obtained at rates of roughly 2×10^3 cpm. The total anode current under these conditions is about 3×10^{-8} amperes. If the counting rate is increased by bringing up the 1.04-mc source, the results shown in Figs. 2, 3, and 4 are obtained. The irregularity in the curves is not statistical but is caused primarily by operator timing errors; the error brackets shown correspond to a timing error of ± 0.2 sec. This error could have been eliminated with timer-controlled scalers, but this refinement was not deemed necessary since the fatigue effect is not masked.

Referring to Fig. 2, data for which were taken with a discriminator setting equal to 40% of the peak Co^{60} pulses, it may be observed that the curve has roughly the same shape as that obtained by d-c measurements at higher average currents—with the usual gradual leveling off as the fatigue rate approaches the recovery rate. However, the exact shape of the curve and the equilibrium level itself at a fixed anode current is strongly dependent on the nature of the differential pulse distribution and on the relative position of pulse discrimination level. For example, with a strongly

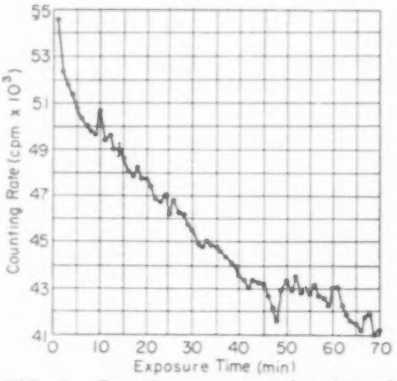

FIG. 2. Counting rate as a function of time for a 5819 tube with a 3.6-rd source at 26 in. and a 1.04-mc source at 14 in. Discriminator set at 40% and anode current 7×10^{-7} amperes

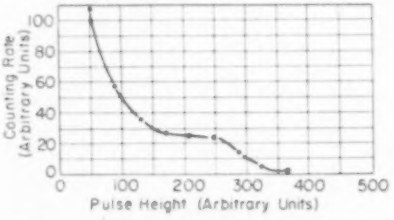

FIG. 1. Differential-pulse-height spectrum of the gammas from Co^{60}. Tube used was an RCA 5819 with average resolution

resolved photopeak under conditions where photoelectric absorption is predominent—I^{131} and NaI(Tl)—the fatigue instability would be considerably smaller with a discriminator setting well below the photopulse height, since most of the area under the differential pulse-

distribution curve would remain above the discrimination level.

If the anode current is increased after an initial fatigue equilibrium, the counting rate will again begin decreasing to a new and lower relative equilibrium, as shown by Fig. 3. This curve, for which the initial anode current was 2.05 $\times 10^{-6}$ amperes, was obtained imme-

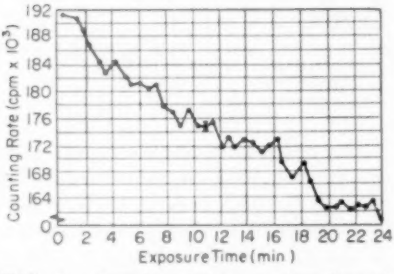

FIG. 3. Counting rate as a function of time for a 5819 tube with a 3.6-rd source at 26 in. and a 1.04-mc source at 8 in. Discriminator set at 50% and anode current 2.05 $\times 10^{-6}$ amperes. Tube pre-exposed for 76 min at 7 $\times 10^{-7}$ amperes

diately after the data for Fig. 2 for which the anode current was 7.0 $\times 10^{-7}$ amperes. For the data of Fig. 3, the 1.04-mc source was moved to a point 8 in. from the crystal (14 in. was used in Fig. 2); the discriminator setting was raised to 50% of the peak Co^{60} pulses to keep the counting-rate register within its capabilities. After each run the 1.04-mc source was removed and a low-rate stability check made with the permanently positioned 3.6-rd source. All such low-rate checks were constant within the counting statistics.

The pulse-height change needed to account for the counting-rate reduction during fatigue may be determined by raising the discriminator level until an equivalent reduction is obtained. Thus, for the tube of Fig. 4, a change in the discriminator setting from 70% of the peak pulse to 71% of the peak pulse changes counting rate from 70,000

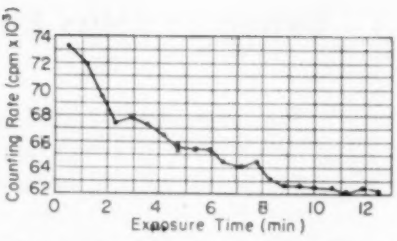

FIG. 4. Counting rate as a function of time for a 5819 tube with a 3.6-rd source at 26 in. and a 1.04-mc source at 8 in. Discriminator set at 70% and anode current 2.25 $\times 10^{-6}$ amperes

to 62,500 cpm. A discriminator change equivalent to a 1.4% gain change due to fatigue therefore results in a counting-rate change of 11%, which is very roughly that observed in Fig. 4. This result is also checked by an integration of the area under the curve of Fig. 1 between the initial discriminator level and an equivalent "fatigued" level.

Thus, to insure stable results from the usual scintillation counter, it is best to hold the total anode current to not more than 10^{-7} amperes. This may best be done by reducing the acclerating voltage on the last 3 or 4 dynodes and plate only,* so as to maintain the high resolution accompanying high collecting voltages on the cathode and early dynodes. The loss in gain resulting from this procedure must then be made up by additional amplification after the multiplier. The gain stability required for reproducible integral counting rates is of the order of 0.1%, an order of magnitude higher than that required for differential counting rates† since a shift in actual pulse height of ~1% is usually tolerable for differential data. —END

* A reduction in the anode voltage will reduce fatigue even at constant last dynode current, an effect first observed by DeBoer and Teves [*Z. Physik* **74**, 604 (1932)].

† It is not implied that some of the actual differential rates will be less affected by gain shifts, but rather that the position on the energy axis of prominent characteristics of the differential spectrum will not be greatly altered, i.e., by ~1%.

Dating of Relics by Radiocarbon Analysis

The radiocarbon in all living things serves as a basis for dating relics by comparison of the activity of the relic with that of two other C^{14} samples of known age. The apparatus and technique described are useful for other applications

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THE POSSIBILITY of continual production of C^{14} in the atmosphere by cosmic-ray-produced neutrons was first pointed out in 1940 by Korff (*1*). In 1946 Libby (*2*), using the available estimates of the rate of production of neutrons by cosmic rays, computed the expected C^{14} concentration, and predicted that it should just be possible to detect it in carbon samples taken from the atmosphere or from material whose carbon was derived from atmospheric CO_2.

Libby, with a number of associates, then proceeded to a successful experimental verification of the prediction of the expected C^{14} concentration in the atmosphere (*3*). It was then that the possibility of age determination was first suggested. Since these pioneering experiments, Libby and Arnold (*4*) have measured and published the ages of well over 100 specimens, including nearly every conceivable kind of relic of the past.

Radiocarbon in Nature

When the incoming cosmic-ray particles, which are mostly protons, strike the earth's atmosphere, they give rise to a complicated hierarchy of radiations —photons, mesons of several kinds, positrons, electrons, neutrinos, the new "V particles," and perhaps other things not yet discovered.

One of the most conspicuous and frequently occurring events in this complex chain is the nuclear evaporation or low-energy star. In this process the nucleus in the atmosphere receives an excitation of from a few to a few hundred Mev when it absorbs a "low-energy" proton, neutron, or meson. As a result, from one to ten, or more, of the constituent nucleons evaporate off. The neutrons and protons come out in about equal numbers, roughly the proportion in which they exist in the nucleus.

The evaporated neutrons, generally not energetic enough to produce further stars, are slowed down by collision in the atmosphere and finally react, for the most part, with nitrogen nuclei according to the equation $N^{14} + n \rightarrow C^{14} + p$. This is a slow-neutron reaction, exothermic by 0.6 Mev.

The C^{14} produced in the atmosphere is quickly oxidized to CO_2. Since the entire biological world derives practically 100% of its carbon, either directly or indirectly, from the CO_2 of the atmosphere, the C^{14} concentration in biological carbon may be expected to be the same as the concentration in the atmosphere. (Some recent evidence suggesting that this statement should be qualified will be discussed later in this paper.)

At death, plants and animals cease to

take up new carbon from the atmosphere. Neither is any C^{14} produced *in situ* in the relic material even though it continues to be exposed to cosmic-ray neutrons. The reason for the latter is: The nitrogen-carbon ratio in the plant or animal, dead or alive, is thousands of times less than the ratio in the atmosphere. The rate of production *in situ*, even assuming the same intensity of neutron irradiation, would be less in the plant or animal than in the atmosphere by that ratio. The age can be found, therefore, by simply determining to what degree the C^{14} has decayed since death. This, with the known half-life of C^{14} (5,568 $\pm$ 30 y), gives the age of the relic.

To see how the C^{14} formed in the atmosphere distributes itself over the earth, it is helpful to examine the world economy of carbon. Figure 1 shows the interrelations of the principal items in the world carbon inventory. Atmospheric CO_2, dissolved CO_2 in the oceans, and biological carbon are considered to be the only significant pools of carbon that are in exchange with one another. The approximate amounts, in metric tons of carbon, are: atmosphere, 8×10^{11}; biological matter (mainly ocean plant life), 1.7×10^{12}; ocean carbonates, 3.7×10^{13} (*5*, *14*).

The rate at which neutrons are produced in the atmosphere by cosmic rays has been estimated (*5*) to be about 2.6 n/sec per cm^2 of the earth's surface, or a total of 1.3×10^{19} n/sec for the whole atmosphere. Making the reasonable assumption that all of these neutrons give rise to C^{14}, and using the half-life of C^{14}, one can easily compute that at equilibrium there should be 80 metric tons of C^{14} in the world. According to direct measurements, only about 0.95 metric ton is accounted for by the C^{14} concentration in the atmosphere. This means, from the simplest possible viewpoint, that the carbon produced in the atmosphere must rapidly (compared to its half-life) become diluted into a body of carbon which is roughly 80 times as much as the amount of carbon in the atmosphere. The quantities given above, while not complete, indicate that the total amount of exchangeable carbon in the world is just about right to satisfy this requirement.

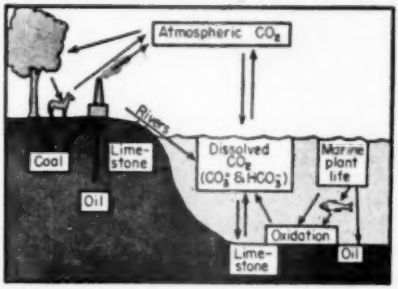


FIG. 1. Interrelations of the principal items in the world carbon inventory

The question of whether exchange between the various carbon reservoirs can be rapid enough to bring about such a dilution has been studied (*5*) by measuring the C^{14} concentration in the various reservoirs and by attempting to "balance the books" on the amounts of stable and radioactive carbon in the various places. The conclusion is that the exchange is rapid enough so the newly produced C^{14} can be considered to be diluted, before it decays appreciably, into all of the exchangeable carbon of the world.

Method of Measurement

Technically, the primary problem in measuring the C^{14} content of a carbon sample is to reduce the background, which is due to local radioactivity and cosmic rays, to a level comparable to the effect produced by the C^{14}.

The activity of contemporary carbon is 16.1 dpm/gm (*5*). Its beta-ray energy spectrum has an upper limit of 154 kev, and the saturation depth for self-absorption is about 20 mg/cm^2. About 0.014 beta rays per cm^2 per min

TABLE 1
Standard-Deviation Errors

Unknown sample (counts)	*Age (years)*	*Standard deviation*	
		plus (years)	*minus (years)*
7,500	5,568	360	340
6,250	11,136	720	630
5,625	16,704	1,400	1,200
5,312	22,272	3,100	2,100
5,156	27,830	8,300	3,900
5,078	33,408	∞	6,600

escape from such a saturation layer of contemporary carbon.

In Libby's G-M counter method of measuring C^{14} (*6*), the sample of purified carbon black is coated on the inner surface of the cathode sleeve in a layer deeper than the saturation layer. This gives the maximum possible count from a given carbon area. When, in this arrangement, the local background is eliminated as far as practical by shielding, and when cosmic-ray counts are cancelled by the anticoincidence method, the real count from the C^{14} in a contemporary sample just about equals the background count. In this respect, our experience parallels very closely these results.

A layer of carbon 300 cm^2 in area can, therefore, be expected to give about 5 cpm over a background which is also about 5 cpm. To indicate the accuracy with which ages can be determined under these circumstances, Table 1 lists standard-deviation errors.

In computing the table it was assumed, as a typical example, that the time was divided equally among three carbon samples: contemporary, unknown, and dead. The contemporary sample was assumed to give a total of 10,000 counts and the dead sample 5,000, corresponding to a run of about 48 hr. The standard deviation for the fraction $F = (C_u - C_b)/(C_c - C_b)$ was computed, and $F = e^{-\lambda t}$ used to express the result in years. In these equations, C_u = unknown-sample counts; C_b = dead-sample, or background, counts; C_c = contemporary-sample counts; λ = decay constant of C^{14}; and t = age.

The standard-deviation error in years is unsymmetrical, and the error on the plus side goes to infinity between the 5th and 6th half-lives. This places an absolute limit on the age of sample that can be dealt with in a 48-hr run. Some improvement in precision can be achieved by dividing the time unequally between the samples, particularly if the age is near one end of the scale. The actual standard deviations may be somewhat higher than those in the table because of the occurrence of systematic errors. The latter are difficult to assess.

Applications of the Method

Besides measurement of the ages of relics, a number of other possible applications of the method are very interesting. The very fact that we have here a method of measuring samples which emit only of the order of 5 particles per day per cm^2 (background is about 24 per day per cm^2) opens up a whole class of experiments not accessible to ordinary counting methods.

Libby's apparatus (*6*) has been used effectively in the search for new natural radioactivities in medium-weight elements. The discovery of the radioactivity of Re^{187} and In^{115} has been reported (*7*, *8*).

An equally important application should be in tracer experiments in which a great dilution or loss of the sample is involved. If, for example, a 10-mc sample of a radioactive tracer were to be diluted by 20,000 tons of nonradioactive material, the activity would still be 20% above the counter background. The recovered sample of diluted material would have to be chemically processed to eliminate the naturally radioactive

elements, and the sample would have to be about 10 gm in weight. In many experiments in agriculture the dilution factor is very great. For example, if a 10-mc batch of radioactive fertilizer were spread on the ground, only one part in two billion would have to appear in each gram (dry weight) of plant material, to be measurable with reasonable accuracy. In all tracer experiments in which the quantity of the end product is large enough to coat the cathode cylinder (about 10 gm), the technique described will provide a factor of at least 100 over the sensitivity of the conventional G-M counter method.

A recently discovered effect which opens up a broad field for study is what appears to be an unexpectedly strong separation of the carbon isotopes in photosynthesis. In experiments reported by Weigl and Calvin (*9*), plants were grown in a controlled atmosphere whose CO_2 contained a measured concentration of C^{14}. They found that the C^{14} concentration in the carbon of the plants was about 10% lower than the concentration in the carbon of the CO_2 in which they grew. Some attempt has already been made toward understanding this on the basis of the details of the structures of molecules involved in the photosynthetic reactions. The experiments were done in an enclosure containing a C^{14}-enriched atmosphere. Similar experiments could, however, be done by collecting naturally grown samples of, say, green plants, shells, bacteria, etc., and by making careful comparisons of the concentrations of radiocarbon in them.

If it should be established beyond question that there is a strong separation of the carbon isotopes in photosynthesis, this fact will have to be taken into account in age measurements, at least in those cases in which comparisons are made between organic and inorganic samples. Fortunately, most ages have been, and will be, determined by comparing the activities of old and contemporary organic samples, so there is not much danger that determinations so far made will have to be revised, in any case.

One possible experiment, which strikes the imagination, would be a global C^{14} tracer experiment. If, in peacetime, we were to explode an experimental H-bomb which would release sufficient neutrons to alter measurably the atmospheric C^{14} content, many facts about the carbon economy of the earth could be learned. The rate of exchange of CO_2 between the atmosphere and the ocean, the mixing between the surface waters and the deep waters of the ocean, the mixing of the atmosphere between the hemispheres, and many other problems might be attacked, provided observers in various parts of the world were ready to make use of the opportunity. The author will not be indiscreet enough even to attempt a scientific guess as to how many neutrons might be released by an H-bomb. The present quantity of C^{14} in the atmosphere is, however, well known (950 kg), so it follows that the release of 7 kg of neutrons would, when captured by nitrogen, raise the C^{14} content of the atmosphere by 10% which would be easily observable. This would be the only peaceful use of the H-bomb yet proposed!

In our own measurements we have taken cognizance of the fact that local and temporary changes in the atmospheric content of C^{14} may already have been produced by the atomic bomb activities. To play safe we have taken for contemporary standards wood grown before the atomic age. Nothing the atomic experimenters can do in changing the C^{14} content of the atmosphere will invalidate the age measuring method. Specimens which died before 1945 will not have their C^{14} content changed, and it will always be possible

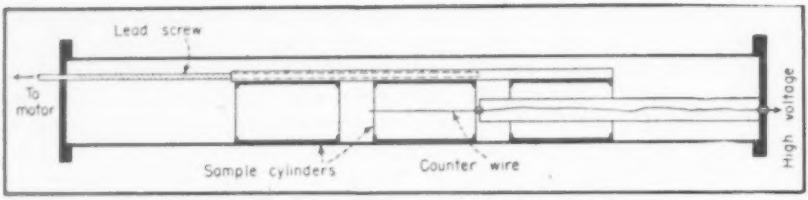


FIG. 2. The main elements of the counter

to obtain pre-atomic-age samples of known date for standards.

Apparatus and Technique

The envelope of the counter consists of a 4-in. seamless steel tube 61 in. long, with flanges and plates at the ends, sealed with "O ring" gaskets. A 1¼-in.-diameter steel tube, cantilevered from one of the end plates, supports the counting wire and its guard structure. Three stainless-steel sample sleeves, 9 in. long and 3¼ in. in diameter are screwed to a piece of ¼ in. brass tubing. A lead screw runs inside this tube and is turned by a reversible motor outside the counter. This moves the assembly of sleeves so that first one and then another of the carbon samples forms the cathode for the counting wire. Figure 2 shows the envelope, sample cylinders, lead screw and counter wire.* A guard structure on the counter prevents beta rays from entering from the cylinders not being counted, and sharply defines the limits of the area of carbon which is counted. The screen electrode between the counter wire and the carbon, which Libby has described (*6*, *10*), is not used in this counter. A clock motor with appropriate cams, microswitches, relays, etc., serves to program the motion of the sample assembly, for example, making it count one hour on each of the three carbon samples, in rotation.

Three self-starting electric clocks and three count registers accumulate the data. When sample No. 1 is in place, clock No. 1 runs and the counts register on register No. 1. When sample No. 2 moves into place, relays switch the power to clock No. 2 and the counts to register No. 2, and so on. Thus, the three times and three counts are totaled separately. After the sample is inserted, the apparatus makes the whole run, usually 48 hr, without further attention.

Background reduction. To reduce the gamma-ray background count due to natural radioactivity in the immediate surroundings, an iron shield made of slabs of 2-in. boiler plate is built up around the counter. It is 8 in. thick at the center part of the counter envelope, and tapers to 4 in. at the ends (see Fig. 3). Since the ends are so far from the active part of the counter it is of little advantage to shield the ends. A bundle of 15 cosmic-ray counters, each 20 in. long and 1 in. in diameter, surround the middle part of the counter envelope. These are in anticoincidence with the carbon counter and effectively eliminate counts from the penetrating cosmic-ray component.

All material contains some naturally radioactive contamination, principally uranium, thorium, and actinium, with their daughter products, and also potassium. Igneous rocks contain 5 to 10 parts per million of uranium and a somewhat greater amount of thorium. (If the uranium and thorium contained in an ordinary granite rock could be made to undergo fission, more energy would be released than would be re-

* Detailed sketches of the counter and electronic circuits can be furnished to anyone who contemplates the construction of such a machine.

leased if the rock were made of solid coal and burned.) This contamination shows up to a considerable extent, of course, in all concrete, mortar, bricks, etc., and consequently the walls of a research room are quite measurably radioactive. Lead, ordinarily thought of as the best shielding material, is more or less radioactive, depending upon its source, because lead ore in most cases occurs in association with uranium and thorium ores. Of the relatively cheap and heavy materials which are suitable for shielding, iron seems to be the most free of radioactive contamination.

Counter circuits. The anticoincidence counting system used is novel in only a few particulars. During the very long unattended runs which have to be made there is the possibility that the voltage threshold of the counter will drift perceptibly. This is not surprising in view of the large area of metal, the rubber gaskets, and the finely divided carbon which are exposed to the gas, all of which can take up or give off gas for a considerable length of time after the counter is sealed. For this reason we use a circuit which automatically regulates the voltage on the carbon counter so as to maintain a constant pulse size (*11*). As a consequence, this holds the operating voltage at a fixed distance above the threshold, even though the threshold may creep due to changes in gas pressure. The cosmic-ray (anticoincidence) counters are permanently sealed, so a fixed operating voltage is used. Because of the extremely low counting rate, scalers are not used ahead of the three registers.

Because of the low counting rate, one can afford the luxury of a long deadtime in the counting system to eliminate spurious counts following closely after the real counts. These spurious counts are of two kinds: those delayed a time interval equal to the transit time of the positive ions from the wire to the cathode (a few hundred microseconds), and

FIG. 3. General view of the apparatus

those which arise because of activation of the cathode by positive ions (*12*, *13*). The probability of the latter kind of count falls off exponentially from the instant of the real count. Both of these effects are more serious in a counter that must be opened and closed frequently than in one which can be cleaned and sealed permanently.

In our system the carbon counter channel is blanked for about 1 msec after each count. The amount by which the background count is reduced by this blanking depends on the particular filling of the counter. Because of the automatic voltage stabilizer and the extended deadtime, reliable counting is obtained within a half hour after filling, and the apparatus may be left to take care of itself for the 48-hr run.

Preparation of samples. The chemical procedure for preparing pure carbon black from relic material is rather lengthy, but for a good reason. It is absolutely essential to separate from the carbon all traces of naturally occurring radioactive substances, particularly potassium and the uranium and thorium families. This is because the number of disintegrations per unit time in a gram of granite rock or in most ordinary soil is about 10 times that in a gram of contemporary carbon, and the number

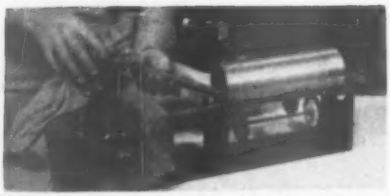


FIG. 4. Pouring the carbon slurry into a rotating sample cylinder

of disintegrations per unit time in a gram of potassium is about 1,000 times that in a gram of contemporary carbon.

In the main, the chemistry is similar to that already published (*6*). The first operation is to make the relic carbon into CO_2, because in this form purification can best be accomplished. If the original material is in the form of a carbonate—shell, for example—it is treated with HCl to produce the CO_2.

If, as is more often the case, the material is cellular—wood, for example—it requires more extensive treatment. It is first roasted in a closed iron vessel to drive off the tars and leave a brittle, charred mass. This is crushed and then leached with acid to remove any carbonates which might have been deposited by water while the material was in the ground. The material is then burned in oxygen to produce the CO_2.

The charring and crushing operation not only facilitates the leaching process, but has been found to be a great help in the burning because there are then no tars present to foul the apparatus during the burning. However, in eliminating the tars in the charring process, there is some loss of weight of the sample; consequently this step has to be omitted in cases in which barely sufficient material is available.

After the CO_2 is produced the treatment of all samples is the same. The CO_2 is purified by means of cold traps. An intermediate step is sometimes used, if there is appreciable tar present, which consists of collecting the CO_2 in ammonia, precipitating it as $BaCO_3$ and driving if off again by adding acid.

The purified CO_2 is next passed over hot magnesium metal, which reduces it to carbon. The magnesium oxide and the excess magnesium are removed by HCl treatment, leaving more or less finely divided carbon. If, at this stage, a portion of the carbon sample is burned to ash, it will be found to yield a residue of magnesium oxide equal, usually, to about 5% of the weight of the carbon, but in some cases running as high as 20%. It strikes one that the removal of such an active impurity by chemical means ought to be quite a straightforward operation, but actually it has been a most exasperating problem. The residual magnesium oxide is in such a stable combination with the carbon that it is not attacked in the slightest by HCl. Libby found that it could be partially removed by heating the carbon to a high temperature and then retreating with HCl. So far the procedure has been to live with the evil, that is, to use the carbon as it comes and, in each instance, to correct the counting rate for the ash content. This has introduced an uncertainty, however, since it involves the assumption that the ash is completely nonradioactive—an assumption shown by experience to be unwarranted. Quite recently we have had the good luck to find a way in which to eliminate the ash, at least down to a fraction of a per cent. Strong oxidation of the sample in near-boiling HNO_3, followed by washing with water does it. Ash contents now range from 0.15% up to 1%.

Physical handling of the carbon. To aid in spreading the carbon in a uniform layer in the cathode cylinder, the motor-driven rotator shown in Fig. 4, was devised. While this is rolling the cylinder horizontally, at about 2 rps, the carbon slurry is poured in and spread with a spatula. The slurry is of just such a consistency that it levels

itself into a uniform layer. The vehicle used is benzene, with mineral oil added in the amount of 3–5% of the weight of the carbon. Benzene has an advantage over water in that traces of it left in the layer after it is put into the counter envelope do not adversely affect the counter behavior, as does water vapor. Oil is an excellent "glue" for carbon, and possesses the advantage that it does not dry hard and pull or check the layer. It also allows the layer to be removed easily with a spatula. The dry weight of carbon sample used in our counter is about 12 gm.

Counting. Of the three sample cylinders, one is coated with "dead" carbon, obtained from coal, and another with contemporary carbon, obtained from recently grown wood. These two are left in the counter permanently. The third cylinder is used for the unknown sample, whose age is in each case determined by comparison with the other two.

To check the possibility that the radioactive backgrounds of the three metal cylinders themselves may differ enough to cause some systematic error, long runs have been made using dead and contemporary samples in the cylinder which normally holds the unknown. It has been found that there is a difference of a few per cent between the backgrounds of the three cylinders. This must be taken into account in the age measurements.

The method of simultaneously using a contemporary and a dead sample, for comparison with the unknown, has an important advantage in that it reduces the computation to one of a pure ratio, eliminating any reliance upon the constancy of the absolute efficiency of the counter. Further, it allows the unknown to be compared in each case with whichever standard it is nearest to in counting rate—the ancient or the contemporary.

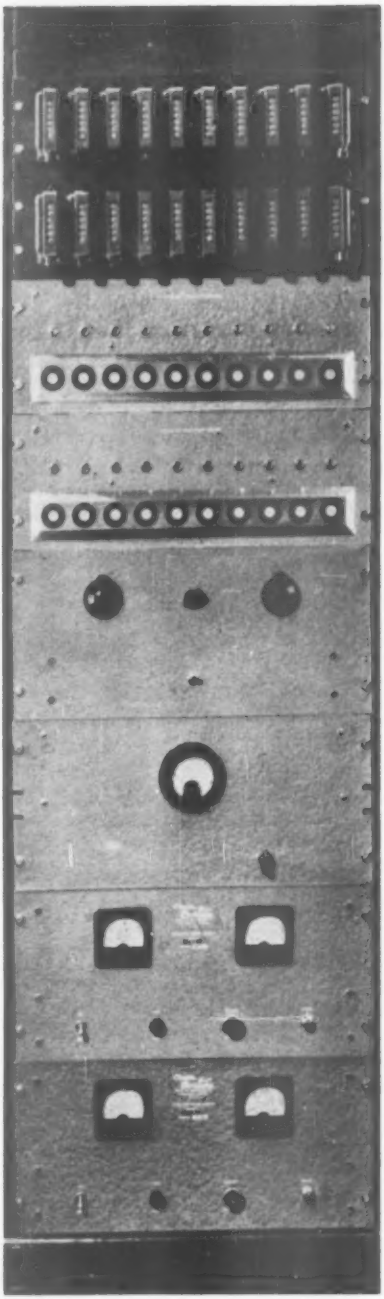
Checks on the operation. In breaking in the apparatus, numerous runs were made using relic material of known age, including both new material and material which had been run by Libby's group. These gave the expected results, consistent with the expected uncertainty due to statistics. A better check on the apparatus, perhaps, is the agreement between runs at different times on the same sample. These have also checked as well as was to be expected from the statistics of the numbers of counts. Up to the time of writing, the work has been devoted largely to improvements in the technique rather than to the measurement of a large number of samples. Age determinations on about 20 samples have been made, and at present the apparatus is being used full time for the determination of dates.

* * *

It is a pleasure to acknowledge the expert assistance rendered by Mr. Earl McDaniel on the construction and operation of the counter, and by Mrs. Gloria Thornton on the chemical preparation of the samples. The project is financially supported by the Michigan Memorial-Phoenix Project.

BIBLIOGRAPHY

1. S. A. Korff, *Terrestrial Magnetism and Atmospheric Electricity* **45,** 133 (1940)
2. W. F. Libby, *Phys. Rev.* **69,** 671 (1946)
3. E. C. Anderson, W. F. Libby, *et al., Phys. Rev.* **72,** 931 (1947)
4. J. R. Arnold, W. F. Libby, *Science* **113,** 111 (1951)
5. E. C. Anderson, W. F. Libby, *Phys. Rev.* **81,** 64 (1951)
6. E. C. Anderson, J. R. Arnold, W. F. Libby, *Rev. Sci. Instr.* **22,** 225 (1951)
7. S. N. Naldrett, W. F. Libby, *Phys. Rev.* **73,** 487, 929 (1948)
8. E. A. Martell, W. F. Libby, *Phys. Rev.* **80,** 977 (1950)
9. J. W. Weigl, M. Calvin, *J. Chem. Phys.* **17,** 210 (1949)
10. W. F. Libby, *Phys. Rev.* **46,** 196 (1934)
11. H. R. Crane, *Rev. Sci. Instr.* **20,** 955 (1949)
12. H. R. Crane, *Phys. Rev.* **75,** 985 (1949)
13. M. L. Wiedenbeck, H. R. Crane, *Phys. Rev.* **75,** 1268 (1949)
14. E. I. Rabinowitch, *Sci. American* **179,** No. 2, 25 (1948)



◀This 20-channel pulse-height distribution analyzer uses as its differential discriminator this specially designed, commercially produced, cathode-ray tube.▶

The system is more versatile, faster, and more stable than conventional pulse analyzers. Adaptation for coincidence pulse analysis, and for measurement of very short half-lives is possible.

A Pulse-Height

By WILLIAM E. GLENN

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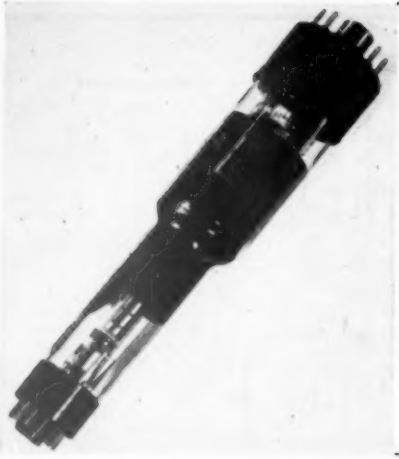
THERE HAS BEEN an increasing need in recent years for pulse-height distribution analyzers. The major application has been the measurement of the energy spectra of various types of nuclear radiation. For alpha particles, the pulses to be analyzed are usually obtained from an ionization chamber. For gamma rays the pulses may come from a proportional or a scintillation counter.

In a previous article* a method of pulse analysis was described which employed a special cathode-ray tube as the differential discriminator. This tube, now available commercially, has a series of collector plates across the

* W. E. Glenn, NUCLEONICS **4**, No. 6, 50 (1949).



Tube Characteristics

Length	10½ in.
Diameter	2 in.
Focus	magnetic
Deflection	electrostatic
Heater	6.3 volts
Anode No. 1	450 volts
Anode No. 2	550 volts
Intensity grid	−30 volts
Intensity grid cutoff	−75 volts
Collector plate	650 volts, 200 μa
Shield plate	550 volts
Deflection sensitivity	.6 volts/channel
Channel-width variation	±1% to ±5% (depending on tube)
Output capacity	1 μμf

Distribution Analyzer

screen end. The shaped pulse to be analyzed is applied to the deflector plate of the tube and the beam is turned on by a gate pulse at the peak of the deflection pulse. The beam is thus turned on at a channel corresponding to the pulse height. The pulse from the collector plate of this channel operates a counter.

This system has the advantages that it is more versatile, faster, and more stable than conventional pulse analyzers. It can very easily be used for coincidence pulse analysis and other special applications.

Since the publication of the earlier article, satisfactory ten-channel cathode-ray pulse-analyzer tubes have been constructed for us by DuMont and a pulse analyzer has been built using these tubes. This pulse analyzer has been in operation for several months and has proved to be very reliable.

The pulse-analyzer tube, DuMont type K1059, has ten equally spaced collecting electrodes across the screen end. The collector plates are shielded from each other by thin partitions. If the beam enters between two of these partitions the collector will collect either the beam current directly or an equal current of secondary electrons emitted from the shield. A fluorescent area is provided on the shield on either side of the last collector plates to allow visual focusing if desired.

Beam current can be increased and focus made slightly sharper by increasing the accelerating voltage. This will, however, reduce the deflection sensitivity.

Circuitry

The circuits used with the pulse-analyzer tube have been improved considerably since the experimental model described previously.

The circuit diagram of the main

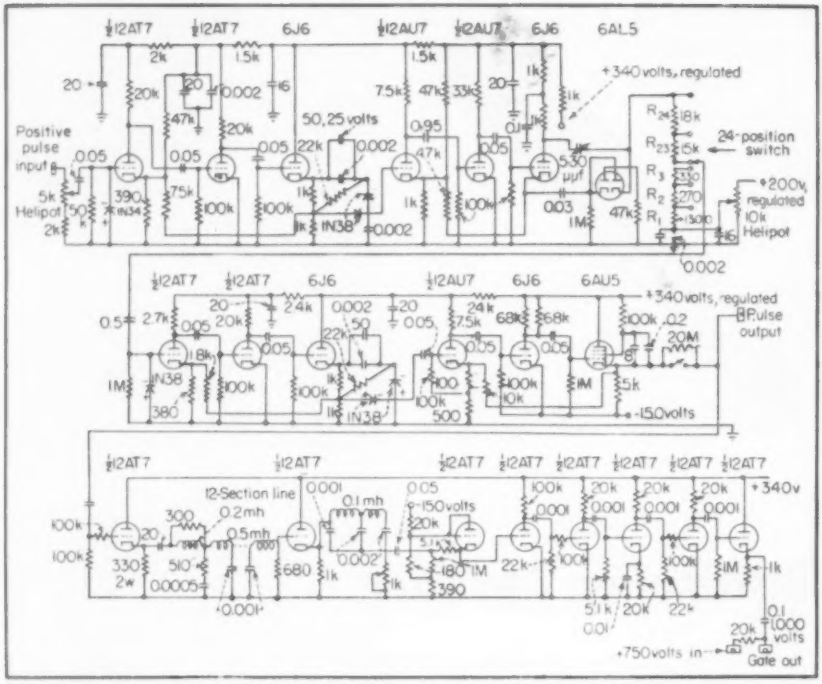


FIG. 1. Circuit diagram for the main amplifier

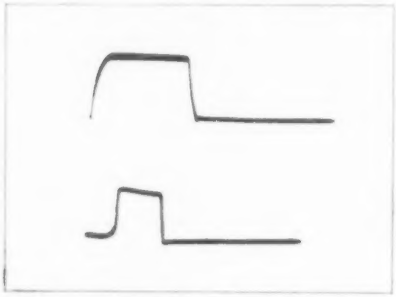


FIG. 2. Top: The shaped pulse that is applied to the deflection plate. Bottom: The delayed gate pulse that is applied to the intensity grid

amplifier is given in Fig. 1. The pulse input to this circuit from the preamplifier should be between 2 millivolts and 4 volts. The rise time of the pulse should be less than 10 μsec and can either decay with a time constant of about 50 μsec or be shaped by a delay-line pulse shaper to a delay of about 25 μsec. Such a pulse shaper was described in the previous article. The delay-line pulse shaper is recommended for shorter deadtime, better operation of the pulse flatteners that appear in the main amplifier, lower intermodulation distortion (nonlinearities due to pile-up of pulses) and better signal-to-noise ratio. Another very successful delay-line pulse shaper consists of an open-ended delay line in series with its characteristic impedance driven by a low-impedance feedback amplifier (usually the first stage of the preamplifier). The shaped pulse is taken off across the matching resistor.

The main amplifier itself (Fig. 1) consists of four feedback amplifiers. The first is followed by a pulse flattener, the

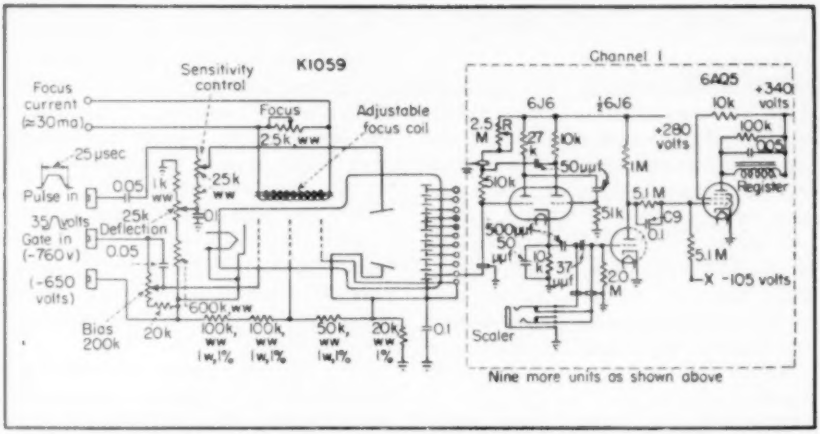


FIG. 3. Circuit diagram for the pulse-analyzer tube and the mechanical registers

second by a neutralized discriminator, the third by a second pulse flattener, and the fourth by an output tube. It also contains a gate circuit to turn on the cathode-ray beam at the peak of the pulse. The operation of the flattener and gate circuit is described in the previous article. In the present gate circuit, a pulse shaper replaces the thyratron used previously to reduce the deadtime of the gate. A neutralized diode discriminator is used in place of the biased triode so that greater stability may be obtained.

In the amplifier arrangement shown, all tubes (other than diodes) are in negative feedback loops. This provides high gain stability and linearity.

Photographs of the shaped pulse to be analyzed and the gate pulse are shown in Fig. 2.

The circuits for the pulse-analyzer tube and mechanical-register amplifiers are shown in Fig. 3. The register circuit consists of a one-shot multivibrator followed by a pulse lengthener which is in turn followed by a power tube used to drive the mechanical register.

The firing sensitivity of the multivibrator is regulated by the variable resistor R. This is adjusted so that the multivibrator will trip at half of the maximum collector-plate current. In this way, if the beam is more than half on a collector, the channel will trip. Since the cathode-ray beam diameter is not zero, there will usually be a very narrow range between channels where either adjacent channels both will trip or neither will trip. This overlap or gap between channels, however, is only about 1–2% of the channel width and is consequently quite negligible.

Provision has been made for the insertion of a scaler between the multivibrator and pulse lengthener. Very high counting rates can be analyzed with only a few scalers instead of as many scalers as there are channels. This is done by plugging in scalers only at points where the counting rate is high.

Applications

Although only 20 channels are in use at present, the pulse analyzer will soon be expanded to 40 channels. Banks of 10 are added merely by feeding the pulse-analyzer tube circuits (Fig. 3) in parallel from a main amplifier circuit (Fig. 1) and providing an appropriate bias on the deflector plates of each cathode-ray tube. When a large num-

ber of channels is used, the mechanical registers will be provided with a motor-driven automatic reset.

The 20-channel unit has been used both with a scintillation counter for the analysis of gamma-ray spectra and with an ionization chamber for the analysis of alpha-particle energies. In operation over a period of several months this pulse analyzer has had excellent short and long-time stability. The main amplifier circuit has been used (with a larger output tube) to drive a conventional 48-channel thyratron pulse analyzer for the past two years with excellent results.

The cathode-ray pulse analyzer can very easily be adapted to coincidence pulse analysis. To use it in this application, the coincidence pulse is applied to the intensity gate circuit. The cathode-ray beam will then be turned on only when a coincidence pulse occurs.

The existing circuits have a deadtime of approximately 30 μsec. This deadtime is determined by the length of the delay line in the delay-line pulse shaper. Faster pulses with a much shorter deadtime could be analyzed with this tube if faster circuits were used.

Another pulse analyzer is now under construction which will have 60 channels. A system suggested by A. Ghiorso and A. E. Larsh is employed which uses five diode discriminators and a single 10-channel cathode-ray-tube pulse analyzer in cascade to obtain 60 channels. Circuits have been designed and tested for this system with satisfactory results. A brief explanation of the system is as follows:

Suppose the height of a pulse is designated by an appropriate number from one to 60. The diode discriminators are set at levels of 10, 20, 30, 40, and 50. The circuit associated with these diodes subtracts off the tens digit from the pulse height. For example, if the height is 27, the circuit will subtract off 20 and leave 7. The remaining pulse is then fed to the cathode-ray tube which reads the units digit. There are 6 registers connected to each channel of the pulse-analyzer tube. These registers are gated by the diode-discriminator circuit so that the only one that trips is the one corresponding to the proper tens digit (in this example, 2).

Since the cathode-ray tube is turned on only in the middle flat portion of the pulse, the transients which occur during the subtraction process do not cause any trouble.

This cascade system, nicknamed the "Jack Rabbit," is cheaper to construct for a large number of channels (probably 40 or more) than the system of stacking 10-channel units. It has the added advantage of having fewer adjustments in regulating the channel width.

The 10-channel circuit in Fig. 3 can easily be used in the measurement of very short half-lives. For this application, the sweep voltage from a synchroscope is applied to the deflector plate and a shaped pulse from a counter is applied to the intensity grid. The synchroscope is triggered when the isotope to be analyzed is formed. This trigger pulse may be obtained from the disintegration of the parent or from the pulsed beam of a particle accelerator. The pulse from the disintegration of the isotope formed then turns on the cathode-ray beam on a collector plate corresponding to its time of decay. The plot of the mechanical register counts will then be an exponential with a decay corresponding to the decay of the sample.

* * *

The author wishes to express his appreciation of the assistance given him in the development of this instrument by A. Ghiorso, H. P. Robinson, A. E. Larsh, D. M. Marton, and other members of the University of California Radiation Laboratory. The work described in this paper was performed under the auspices of the Atomic Energy Commission.

Estimates on the Concentration of Radioiodine in Sewage and Sludge from Hospital Wastes

The probability seems remote that any one hospital will discharge regularly as much as 200 mc of waste per day into the sewage of a large city. At this rate, the dilution needed to reduce the activity to safe limits is no major problem

By C. C. RUCHHOFT* and SERGEI FEITELBERG†

HEALTH AUTHORITIES, noting the increasing use of radioisotopes for human therapy, are expressing concern over the disposal of radioactive liquid wastes from hospitals into municipal sewerage systems.

Recently, Scott (*1*) estimated that the radioactive wastes discharged from the Medical Center of the University of California at San Francisco might result in a concentration of as much as 0.1 microcurie per gram of sewage sludge. This sludge, he stated, could be hazardous when used for fertilizer.

In view of the concern imparted by Scott's paper, it was considered worth while to re-examine the amounts of iodine-131 and phosphorus-32 distributed to large centers of population in the United States and consider implications of the discharge of such quantities of wastes into domestic sewerage systems. Data on shipments of these two isotopes to hospitals in six large cities for the six-month period January 1 to June 30, 1950, were obtained through the courtesy of G. W. Morgan of the AEC Isotopes Division at Oak Ridge. See Table 1. A total of about 70 curies of these isotopes were obtained by the six large cities for therapeutic and tracer purposes. The records of the Isotopes Division show that the shipments during the last half of the year were similar to those shown here.

The last column in Table 1 shows the number of gallons of water required to dilute the weekly wastes from these isotopes (assuming regular reception, disposal without decay, and complete mixing) to the 100 μc/liter maximum permissible short-period contamination level, which was accepted by the Subcommittee on Waste Disposal (*2*).

In Table 2 the volumes of water needed to dilute the isotope wastes to the 100-μc standard are compared to the daily average water consumption for the city. The last column shows that discharge of the isotopic wastes from hospitals into the domestic sewage will amply dilute the activity below the standard of 0.5 μc/liter suggested in the Interim Recommendations (*3*).‡

In the case of the inland cities, like Chicago and St. Louis, the sewage is further diluted by discharge into the Illinois River and the Mississippi River,

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EDITOR'S NOTE: The authors of this paper are members of the Subcommittee on Waste Disposal and Decontamination of the National Committee on Radiation Protection.

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‡ The fact that the several sewage plants in some large cities might receive different proportions of the radioisotopes discharged would not alter the situation materially.

TABLE 1

Examples of Shipments of I^{131} and P^{32} to Selected Cities (January 1 to June 30, 1950)

City	*Isotope*	*Total shipments*	*Total amount received (mc)*	*Millicuries at equilibrium*	*Gallons of water to dilute isotopes received each week to 100 μc/liter**
New York	I^{131}	171	24,099	1,520	2,449
	P^{32}	73	4,393	497	446
St. Louis	I^{131}	71	6,511	410	662
	P^{32}	15	46	5	5
Chicago	I^{131}	56	21,583	1,361	2,193
	P^{32}	56	3,485	394	351
Los Angeles	I^{131}	50	5,456	344	554
	P^{32}	21	1,058	119	108
New Orleans	I^{131}	15	1,148	72	117
	P^{32}	15	536	62	54
San Francisco	I^{131}	18	1,530	96	155
	P^{32}	8	165	20	17

* Standard recommended for contamination of short duration (*2*).

TABLE 2

Concentration of I^{131} and P^{32} to Be Expected in Sewage of Six Large American Cities

City	*Average dilution water needed per day to dilute activity to 100 μc/liter—assuming no decay (gallons)*	*Water consumption of city per day (million gallons)*	*Activity from I^{131} and P^{32} after uniform dilution by volume of water used per day (μc/liter)*
New York	413	925	0.4×10^{-4}
St. Louis	95	160	0.6×10^{-4}
Chicago	363	900	0.4×10^{-4}
Los Angeles	94	150	0.6×10^{-4}
New Orleans	25	60	0.4×10^{-4}
San Francisco	25	100	0.25×10^{-4}

and drinking waters are not taken from these streams for considerable distances below the discharge. In the case of the other four cities, the sewage is amply diluted by discharge into the sea. Because of the relatively short half-lives of these two isotopes and the additional dilution when the cities' sewage is discharged into streams and the sea, the possibility of dangerous concentrations of these isotopes in fishes seems very remote indeed.

Since Scott used the University of California Medical Center at San Francisco as a case in which it appeared that dangerous quantities of wastes might result, it is pertinent to review carefully the situation there. For this purpose, additional information† was sought on the discharge of I^{131} from the Medical

† This information was obtained in 1950 through the cooperation of F. E. DeMartini, Senior Sanitary Engineer, California Drainage Basins and Great Basin Drainage Area, U. S. Public Health Service, at San Francisco.

Center, on the sewage flow at the sewage plant which receives these wastes, and on the method of treatment and sludge production.

It was learned that this Medical Center is currently discharging approximately 1 mc/day of activity in the wastes reaching the sewer. The Richmond-Sunset Sewage Treatment Plant at San Francisco serves the sewerage system on which the Medical Center is located. The U. S. Veterans Hospital at Fort Miley is also served by this system, but it discharges less waste than the University's Medical Center.

The Richmond-Sunset plant serves a total population of 220,000 with a dry-weather flow of 12,500,000 gal/day. The plant is designed to serve an ultimate population of 300,000 and to take a flow of 20,000,000 gal/day. The plant has the following units: Bar racks, mechanically cleaned grit and grease tanks with a detention period of ten minutes; flocculation tanks with mechanical mixing provided; sedimentation tanks with a two-hour detention period; primary and secondary sludge digester tanks; elutriation tanks; and chlorination facilities.

Screenings are incinerated, and incinerator gas is used to agitate the raw sewage as well as to absorb odors from the gas. The grit is washed with sewage and hauled to a dump. The grease and primary sludge from the sedimentation tanks are collected in a sludge hopper and pumped to the primary digester. Approximately 80,000 gal/day of sludge are produced. Sludge-digester capacities are 2,100,000 gal for the primary and 1,000,000 gal for the secondary, thus providing theoretical digestion periods of 26 days and 12 days, respectively. This allows a theoretical 38-day decay time in the sludge for the I^{131} before the sludge is filtered and used as fertilizer.

The primary digester has mechanical mixing and recirculation. Sludge drawn from the primary digester is elutriated with sewage effluent before passing to the secondary digester which is actually used as a storage unit.

Ferric chloride is added to the sludge as a conditioner prior to filtration on vacuum filters. The average moisture content of the filter cake is 70%. The filter cake is used as a fertilizer, primarily in Golden Gate Park, but about 10–15% of the production is used by the public. The sludge is utilized within a very short time, a matter of days after it is produced.

On the basis of this information, the average sewage flow at this plant is 4.73×10^7 liters/day in place of the 2.7×10^7 liters/day as estimated by Scott. In other words, the I^{131} is diluted in about 75% more sewage than was considered by Scott.

On the basis of 80,000 gal/day of sludge produced, it is estimated that 5,000 kg of sludge filter cake are produced per day after a digestion period of 38 days. This would provide a decay period of at least four half-lives for the I^{131} in the digesting sludge.

Table 3 gives data calculated on the basis of the present I^{131} discharge of 1 mc/day; the maximum discharge approved by the California Medical Center of 50 mc/day; the maximum discharge of 200 mc/day suggested by the Interim Recommendations; and an assumed discharge of 1,000 mc/day as used in Scott's paper. The mean concentration of I^{131} that would be obtained in the sewage if the waste is discharged to give a uniform dilution, as given in column 3 of Table 3 is no more than the maximum limit suggested in the Interim Recommendations, i.e., 0.5 μc/liter, for all discharges from 1 to 1,000 mc/day.

Scott estimates that 27 μc/liter may be obtained in the sewage with a discharge of 1,000 mc. Two considerations, however, make this figure of little practical importance. First, sludge as fertilizer is not instantly converted into

TABLE 3

Calculated Estimates of I^{131} Concentrations that May Be Expected in the Sewage and Sludge at the Richmond-Sunset Plant, San Francisco*

Basis of estimate discharge per day	*Discharge of I^{131} waste (mc/day)*	*Mean concentration of I^{131}† in 12.5-million gallons of sewage (μc/liter)*	*Mean concentration of I^{131} in 5,000 kg of filter-cake sludge produced daily‡ (μc/gm)*
Present discharge	1	2×10^{-5}	2.05×10^{-7}
Maximum approved by Medical Center Committee	50	1×10^{-3}	1.02×10^{-5}
Maximum suggested by Interim Recommendations	200	4×10^{-3}	4.1×10^{-5}
Assumed in Scott's paper	1,000	2×10^{-2}	2.05×10^{-4}

* Based on assumed discharges of I^{131} from the Medical Center of the University of California.
† Discharged and diluted uniformly.
‡ Assuming a 1 % removal from the supernatant and a sludge digestion time of 4 half-lives for decay.

edible plants, but a period of not less than 8 half-lives of I^{131} elapses before this takes place, so that the specific activity at this time is effectively reduced more than one hundredfold. Second, no single shot discharge of 1,000 mc is likely to occur in therapeutic use of I^{131}. A discharge of 1,000 mc would occur if not less than 10 thyroid cancer patients are treated in a single day. None of them is likely to discharge more than 45 mc in a single bladder evacuation. The probability of this happening simultaneously with all patients need not be considered. Were the urine of such patients collected in a laboratory, it should not be discharged simultaneously by a laboratory worker, since he would in doing so exceed the permissible daily radiation exposure.

The concentrations that may be expected in the sewage are dependent to a large extent upon the manner in which the waste is discharged. The maximum concentration of I^{131} that may be reached in any system will depend upon the rate of discharge of the waste and the dry-weather sewage flow. In any case, it would be advantageous to discharge the waste at a rate proportional to the sewage flow in the system.

Since the average flow is not uniform and varies materially, it would be desirable to discharge the waste of high activity, say above 50 mc, produced at hospitals at a uniform rate over the whole day or at least over the daylight hours. This can be done by providing a constant-level, fixed-orifice device arranged to discharge the waste at a uniform rate into the sewer over the desired period. A simple expendable device of this sort is described in the recently issued NBS Handbook 49 (*2*) and is reproduced here as Figs. 1 and 2. It easily improvised in any laboratory.

In view of the low present discharges of these wastes into the sewer by the Medical Center, it is not believed that such a device would be necessary. However, if the daily discharge of I^{131} at this Center reaches 200 mc/day or more, it would be highly desirable to install a constant-level discharge device.

At this point, it may be useful to consider under what circumstances a discharge of 200 mc/day might occur. Since large amounts of I^{131} are used only in therapy, let us examine the discharge by patients treated for Graves disease and thyroid cancer. A patient treated for Graves disease excretes during the first day an average of 3 mc. A 200-mc discharge, therefore, represents 67 patients per day, or about 20,000 patients per year (somewhat less due to need for repeated treatment courses). In treatment of thyroid cancer, 200 mc would be discharged by 2 patients. This corresponds to 600–700 treatments a year, or, since patients with thyroid cancer may receive repeated therapy courses 5 to 10 times, to about 100 treated patients a year. Not more than about 20% of patients with thyroid cancer are considered suitable for I^{131} therapy. Therefore, 200 mc may be discharged daily if not less than 500 patients with thyroid cancer are seen annually.

No reliable statistics on incidence of Graves disease or thyroid cancer in the general population are available. Still, it is unlikely that there will be seen at the Medical Center in any single year either 20,000 patients with Graves disease or 500 with thyroid cancer, or any combination of the two diseases to add up to a 200-mc daily discharge.

I^{131} Concentrations in Sludge

A number of factors must be considered in estimating the possible I^{131} concentrations in the sludge that is produced. Scott assumed, for purposes of illustration, that all of the I^{131} would be concentrated in sludge. On the basis of our present information, this assumption is untenable. We know, for instance, that the proportion of radioactive or any other material that will be adsorbed on the sludge is dependent upon the character of the material adsorbed, the character of the sludge, the quantity of sludge present, the period of contact between the supernatant and the sludge, and the temperature.

With activated sludge, which has a very much higher adsorption power than raw sludge, it requires 2,000 to 3,000 ppm of sludge to adsorb 95% of small quantities of plutonium during a 24-hour contact (aeration) period (4). It will be instructive to compare the present situation with that mentioned above for activated sludge. In this

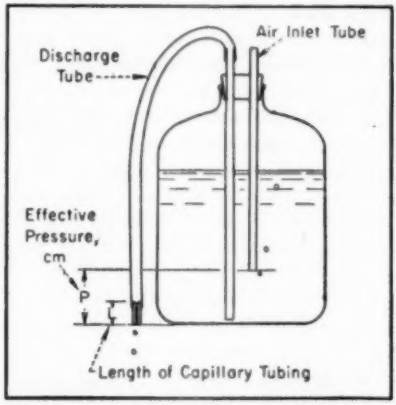

FIG. 1. Gallon bottle set up for constant pressure drip discharge

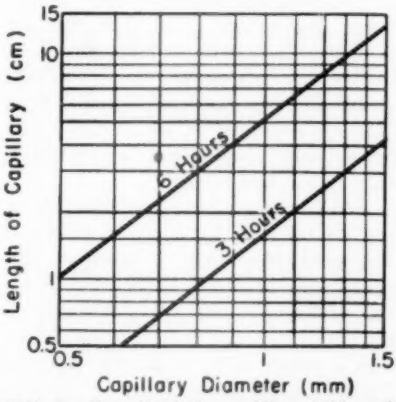

FIG. 2. Length of the capillary tubing of varying diameter for 3-hour and 6-hour discharge time of one gallon bottle with a flow pressure of 5 cm water

case, there will be present no more than 100 or 200 ppm of fresh sludge (with poor adsorbing qualities). This sludge will remain in contact with the sewage only during the two-hour settling period. Therefore, since this sludge with poor adsorbing qualities is present in only 10% of the concentration, and for only $\frac{1}{12}$ the time period, very little concentration of I^{131} can be expected.

The work of Setter *et al.* (*5*) showed that when urine samples collected within the first 24 hours after diagnostic tracer treatments were added to sewage and the solids were settled, very little of the activity was removed from the supernatant. In six experiments of this kind, the activity removed from the supernatant varied from 0 to 3.7%, with a mean removal of 0.64%. Similar experiments to determine the extent to which I^{131} could be concentrated by raw sewage solids during contact and settling were carried out with organic I^{131} compounds with similar results.

In contrast to the assumption made by Scott, it has been shown at the Environmental Health Center that practically all of the I^{131} discharged into sewage will remain in the effluent when the sewage is given primary treatment, as at the Richmond-Sunset Plant. Some concentration of I^{131} can be expected when sewages receiving these wastes are treated by the activated-sludge process. The concentration that may be expected in such cases will depend upon a number of factors which vary from plant to plant.

However, because of great dilution in the sewage before the I^{131} reaches the treatment plant and because of the decay time involved, there need be no fear of hazard from either internal or external exposures in activated sludge that is produced by such cities as New York, Chicago, Milwaukee, etc.

To estimate the activity in the digested sludge at the Richmond-Sunset Plant, it was assumed that the 80,000 gal of raw sludge produced daily would retain the activity of an equal volume of sewage and remove 1% of all the activity in the 12,500,000 gal/day flow. It is also assumed that the I^{131} in the sludge liquor would decay by 4 half-lives during the digestion period but that all remaining activity in the wet sludge would be retained in the sludge cake after conditioning and filtration.

On the basis of these assumptions, column 4 in Table 3 shows that the activity to be expected in the sludge with the present waste discharge is 2.05×10^{-7} μc/gm. This quantity is hardly sufficient to be distinguished from background. In fact, even with a daily discharge of I^{131} of 50 mc/day at the Medical Center, it is doubtful whether any activity above background could be detected in the sludge cake at the Richmond-Sunset Plant because of the self-adsorption by the sludge, as long as the wastes were being discharged relatively uniformly.

In place of an activity of 0.1 μc/gm of sludge, according to our estimates, a daily discharge of 1,000 mc of I^{131} at the Medical Center would result in an activity of only about 2.5×10^{-4} μc/gm in the sludge cake under the conditions of operation at the Richmond-Sunset Plant.

BIBLIOGRAPHY

1. Kenneth G. Scott. Radioactive waste disposal—how will it affect man's economy?. NUCLEONICS **6**, No. 1, 18 (1950)
2. Recommendations for Waste Disposal of P^{32} and I^{131} for Medical Users (National Bureau of Standards Handbook 49; prepared by Subcommittee on Waste Disposal and Decontamination of the National Committee on Radiation Protection). (Govt. Printing Office, Washington, D.C., 1951)
3. Interim recommendations: Disposal of radioactive wastes by non-AEC users. NUCLEONICS **5**, No. 2, 22 (1949)
4. C. C. Ruchhoft. The possibilities of disposal of radioactive wastes by biological treatment methods. *Sewage Works J.* **21**, 877 (1949)
5. L. R. Setter, J. D. Tsivoglou, J. S. Nader. The distribution of I^{131} wastes in a sewage treatment process. Activity Report No. 4, 6-10, Environmental Health Center, U. S. Public Health Service, Cincinnati, O. (1950)

Radioisotopes Techniques Conference Papers

Here are two more papers originally presented to the Radioisotopes Techniques Conference which took place at Oxford, England, from July 16–20, 1951. These papers, as well as the four published in the November* NUCLEONICS, *were selected for their special interest to our readers. A general report on the conference proceedings appeared in the October* NUCLEONICS *in a special article by J. L. Putman.*

Oxford, 1951

Measurement and Handling of Radioactive Materials for Therapeutic Use†

Present techniques used in the measurement of radioisotopes for therapeutic purposes are limited in accuracy. The importance of absolute measurements and the requirement of calibrated instruments are discussed. The methods used at a British hospital to overcome measurement and handling difficulties are outlined

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A CLINICAL department engaged in radioisotope therapy encounters problems that differ from those presented by laboratory use of radioisotopes. Only limited facilities for measurement and handling may be available in a clinical department, but a considerable variety of isotopes with activities ranging from a microcurie to several curies may be used. No matter what the activity, there must be no possibility of serious error in measurement and no undue hazard to personnel.

At the Royal Cancer Hospital, measurement and handling techniques have been developed to meet the requirements imposed by clinical use. These techniques, and the philosophy behind them, are discussed in the following sections.

Measurement

In radioisotope therapy, the aim of the physicist should be to specify the dose delivered to the tissues of the patient with an accuracy comparable to that now obtained in X- and gamma-ray therapy. There is much to be done before this can be realized. The activity (or its equivalent) of the radioactive material would have to be known

* Proceedings of the conference, arranged by the British Atomic Energy Research Establishment, will be published by H. M. Stationery Office, London.

† Paper presented at the Radioisotopes Techniques Conference, Oxford, England, July 17, 1951.

with an accuracy of ±10% or better. At the present stage, ±5% seems to be a more reasonable figure to aim at.

A figure for the activity of a sample is frequently supplied by the distributors. But, since the responsibility for the amount of material administered to a patient undoubtedly rests with those carrying out the administration and not with the suppliers of the material, every sample must be measured in the clinical department.

Absolute measurements. Since the object of activity measurements is to estimate the dose delivered to the tissues during therapy, the total beta and gamma energy emitted by the source must be known. This requires an absolute measurement.

An exception to this occurs when radioisotopes are used as discrete gamma-ray sources, with the beta radiation being negligible or eliminated by a filter. Then it is sufficient to express the activity of the source in terms of the dosage rate at a given distance from it. For gamma emitters with known disintegration schemes, however, the activity of the source can then be found. Medical-physics departments with experience in radium gamma-ray measurements are often equipped to carry out these measurements. Results obtained by different institutions usually do not vary more than 3 or 4%.

When radioisotopes are administered internally, the beta radiation almost invariably makes the major contribution to the total dose. Unfortunately it is considerably more difficult to measure the rate of beta-particle energy emission from a source than it is to measure the gamma emission.

Gray (*1*) has devised one elegant method for beta measurements, but it cannot be considered suitable for routine work. In fact, it is generally more satisfactory, in cases where the beta emission is most important, to express the activity in terms of the absolute disintegration rate—in curies or fractions of a curie. This may well be the more convenient method in the gamma case also, although it is not essential.

A variety of methods exists for absolute measurement in terms of the disintegration rate. Direct methods include the beta-gamma coincidence method, and beta counting by 4π or defined-solid-angle methods. Indirect methods, which usually involve an accurate knowledge of the energy of the radiations, include gamma ionization and beta ionization methods, the measurement of the charge carried by the beta particles, and calorimetric methods.

The accuracy claimed for each of the absolute measurement methods is of the order of 1–5%. But a comparison of results obtained with a number of these methods at the Atomic Energy Research Establishment, Harwell, Berkshire; the National Physical Laboratory, Teddington; the Medical Research Council, Radiotherapeutic Research Unit, Hammersmith; and the Royal Cancer Hospital, however, showed that differences of the order of 10% occurred in measurements of solutions of Na^{24} and of P^{32}. For other isotopes with less well established nuclear constants, the differences are likely to be much greater.

The importance of reducing these differences to supply precise information about the dose delivered during treatment is clear. In addition to absolute measurements of the activity, an accurate knowledge of the average energy of the radiations is required. The determination of the mean beta and gamma energy emitted by an isotope may involve a detailed study of its disintegration scheme. In fact, the study of isotope disintegration schemes is frequently an essential preliminary to therapeutic use of these isotopes.

Routine measurements. Absolute measurements on all samples to be used clinically are time consuming. If the activities involved are high, such meas-

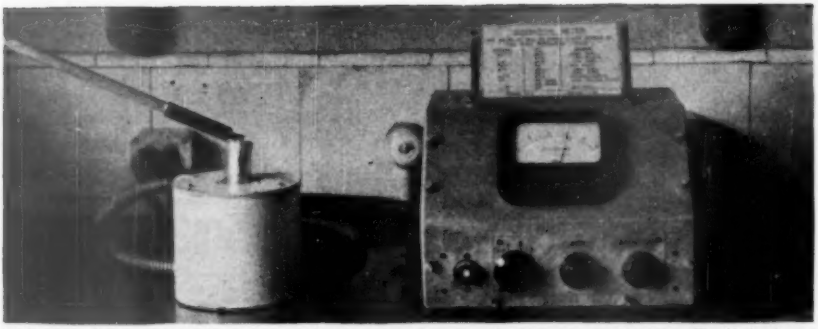

FIG. 1. Direct reading meter for measurement of gamma emitters. Radioisotope container is placed in a cavity within the ionization chamber at left; the activity is indicated on calibrated dosage-rate meter at right

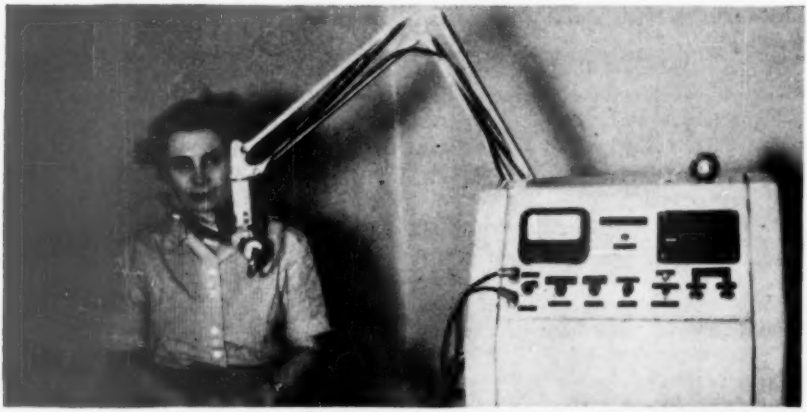

FIG. 2. G-M counting system adapted for clinical use. The counter is held at the end of the extension arm; cabinet holds power supply, scale-of-100 and a count-rate meter

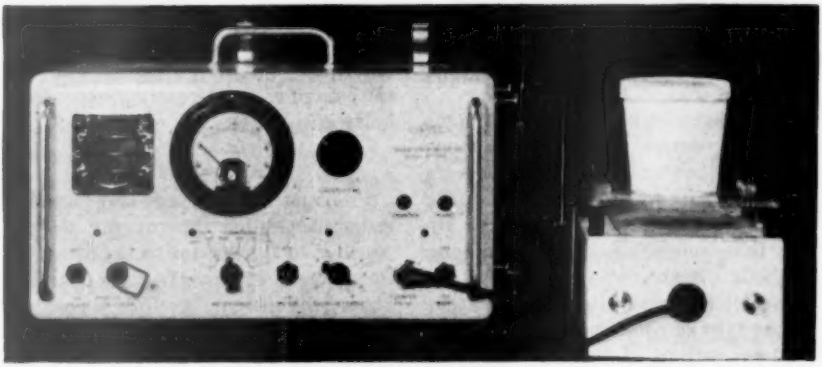

FIG. 3. Arrangement for measurement of activity of excreta. Carton of feces is placed in a specified position relative to a shielded counter, as shown at right. The counter is connected to a count-rate meter

urements may be impracticable because personnel must be protected. A large fraction of the dose received by personnel in the preparation of samples for therapeutic use is received at the measurement stage, unless fully adequate facilities are available.

Once a sound basis for absolute measurement has been established, routine measurements can usually be more safely performed with reliable, calibrated instruments. These instruments should meet the following requirements:

1. Their performance should be reliable and should be checked before each measurement with suitable long-lived standards.

2. The geometrical conditions of measurement should be quickly and accurately reproducible.

3. The measurement should take a short time to perform and should be easy to interpret.

4. The operator should be protected from undue exposure during the course of the measurement.

5. The range of the instrument should be wide, and a relative accuracy of 2% should be possible.

Instruments now in use. These conditions are not difficult to meet for the measurement of gamma-emitting samples. The instrument shown in Fig. 1 covers the range 2–2,500 mg radium equivalent; it has been in use at the Royal Cancer Hospital in London for two years (*2*).

Unfortunately, no similar instrument has been devised for beta emitters. While the protection problem loses its seriousness in this case, most of the substandard methods now in use are very time-consuming. Bremsstrahlung methods (*3*) are not very satisfactory because they depend to a great extent on the type of container used and they take no account of the distribution of activity within the solution.

The most widely used instrument in Great Britain is probably the liquid counter designed by Veall (*4*), but it has a number of disadvantages. High dilutions are required for therapeutic solutions; there is no entirely reliable method for checking the performance of the counter (and unaccountable changes in calibration have occurred); and beta emitters with a maximum energy below 0.4 Mev cannot be measured at all.

A more satisfactory and reliable method that involves no more time is to evaporate aliquots of the solution on metal dishes and measure the activity in a beta electroscope under specified conditions. This method would be greatly simplified if it could be accomplished with liquid sources, and Failla (*5*) does, in fact, use a Lindemann electrometer system for this purpose.

In assessing the dose, the distribution of the isotope within the body and the rate of excretion must be taken into account. If the isotope emits gamma rays, external distribution measurements can yield valuable information. The Geiger-counter system used for this purpose at the Royal Cancer Hospital is shown in Fig. 2.

Rapid methods for measuring highly active excreta are important and, particularly in the case of I^{131}, essential. The calibrated Geiger counter and count-rate meter shown in Fig. 3 have been found suitable for this measurement. By specifying the position of the container for the excreta, reproducibility is obtained.

Handling

Problems encountered in handling radioisotopes for therapy are usually peculiar to the special techniques used for different treatments. No complete general discussion, therefore, is possible. Instead, some of the therapeutic techniques now used at the Royal Cancer Hospital with liquid and solid samples will be described. Since one of the

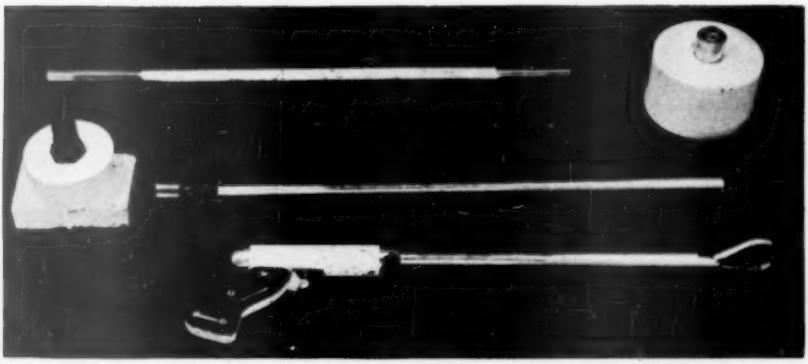

FIG. 4. Remote-control opening tools. Top tool is used to open irradiation cans; too in center is used to open bottles. Lead shields hold containers during opening. Tool at bottom is for gripping souces at a distance

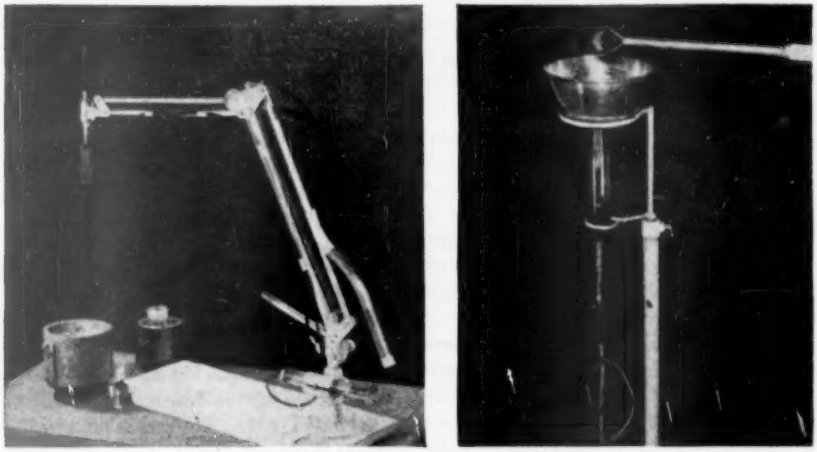

FIG. 5. Left: Remote-control pipette being used to transfer a solution of Au^{198} as red gold colloid to container for administration. Right: Apparatus used for administration of colloidal gold under sterile conditions in the operating theatre

most important criteria in designing a handling operation is the exposure of personnel to radiation, the order of magnitude of the dose received by the personnel using these techniques will be noted.

Handling liquids. Most of the radioactive materials required for therapeutic purposes at present are used in solution form. In the case of pure beta-emitting solutions, the protection problem is relatively easily overcome by the use of suitable remote-control pipetting and handling devices. If high activities of gamma emitters are used, however, speed, distance, and shielding must all be used if the doses received by personnel are to be kept small.

In treating carcinoma of the thyroid, 100–200 mc of I^{131} are frequently used. After the radioisotope sample has been measured in the gamma ionization chamber shown in Fig. 1, the only operation required is opening the con-

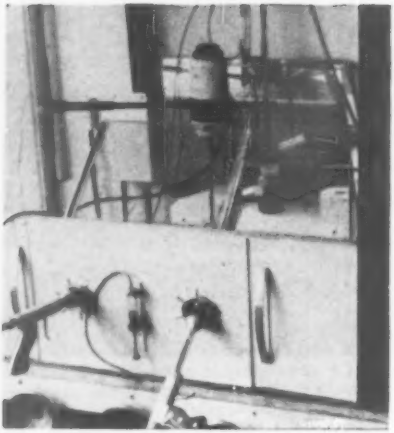

FIG. 6. Lead-shielded fume cupboard equipped with manipulators. Mirror in back of cupboard shows image of 800 mc of Br^{82} as $CaBr_2$ salt being poured from a can and dissolved in water. Electric stirrer is used

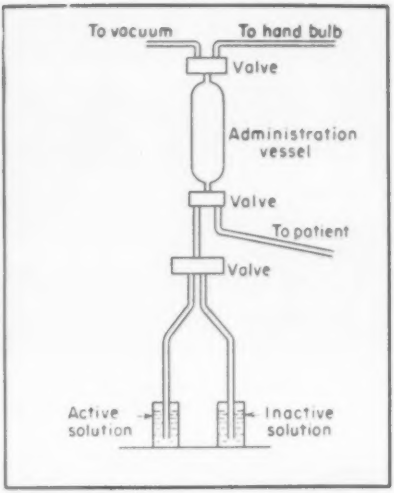

FIG. 7. Apparatus used to administer highly active gamma-emitting solutions for intracavitary irradiation of the bladder

tainer. This is accomplished by using a hexagonal-holed lead block to hold the sample container and a long-handled tool to remove the cap. This and a similar tool for opening irradiation cans are shown in Fig. 4. The dose received in handling I^{131} in this fashion usually does not exceed 1 mr.

Similar activities of Au^{198} in the form of red gold colloid are introduced into the pleural and peritoneal cavities for the treatment of pleural and peritoneal carcinosis. The ampule containing the radioisotope is opened in its lead container, and the desired amount of solution is removed with the remote-control pipette shown in Fig. 5. An aliquot is taken for measurement purposes because a measurement of the total gamma activity of the sample does not take into account the appreciable fraction of the colloidal gold that may have precipitated.

The colloid is administered in the operating theater under sterile conditions. The apparatus shown at the right in Fig. 5 is used. In our experience, no more than 5 mr need be received by personnel during the whole of this operation.

For intracavitary irradiation of the bladder, amounts of Br^{82} or Na^{24} giving gamma dosage rates 20 to 30 times greater than in the case of I^{131} or Au^{198} are being used (*6*). The sample is irradiated in the form of a salt. Its activity is about 800 mc; this is measured in the gamma ionization chamber. Long tongs are used to hold the can, as shown in Fig. 1. The can is then transferred to a lead-shielded fume cupboard equipped with long manipulators (Fig. 6). The cap is removed and the salt is dissolved in a known volume of water. An electric stirrer is used to hasten the process.

The container is then transferred to the apparatus diagrammed in Fig. 7; this apparatus is shielded with two inches of lead. A vacuum created by a pump is used to draw the solution into the upper container; pressure applied from a hand bulb at a distance is used to force the solution into a balloon previously inserted in the patient's bladder.

An important precaution is that the

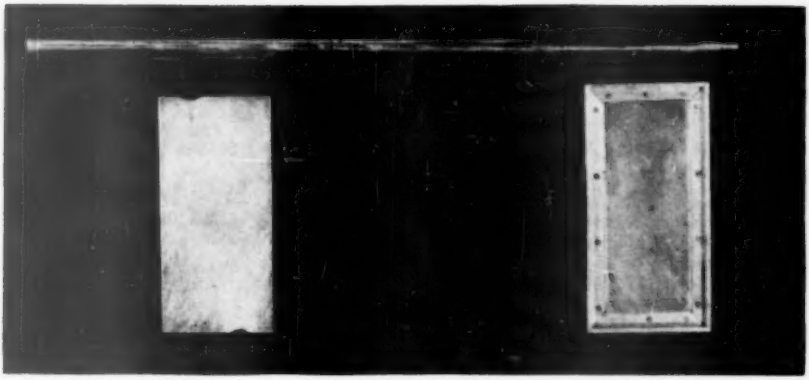

FIG. 8. Duralumin frame and lead-rubber shielding is shown with suction-pad tool used for handling sheets of P^{32} polythene

procedure is run through with an inactive solution first before each treatment.

The progress of the introduction of the active solution is watched in mirrors. The complete technique is accomplished with no more than 15–20 mr being received by each operator, five of whom share the work between them. The gamma dosage rate from the source used is about 1,200 mr/hr at 1 meter, and the tolerance dose specified means that no operator comes within 1 meter of the unshielded source for more than 1 minute. Our experience with all techniques involving gamma radiation indicates that the dose received by the hands averages about four times that received by the body.

Handling solids. Solid sources pose quite a different set of problems. A good example of these problems is provided by the use of P^{32} incorporated as red phosphorus in a polythene sheet for use as a flexible superficial applicator. This method is preferred here to the more common one of using blotting paper soaked in P^{32} (*7*).

At present, four 6 × 3-in. sheets of the plastic are wrapped in polythene and tied with aluminum wire and irradiated. This active package is transported in a wooden box and is opened by cutting the wire.

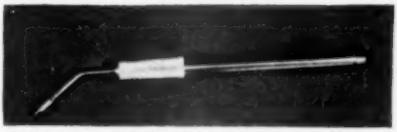

FIG. 9. P^{32}-Bakelite eye applicator mounted in steel holder

An active sheet is laid in a Duralumin frame by using a long tool with a suction pad at its end. Over this is laid a sheet of flexible lead rubber gummed on the under side; this absorbs 98% of the beta radiation. The frame is closed with another Dural sheet (Fig. 8). The other side of the frame is opened and the surface dosage rate (usually about 2,000 r/hr) determined, using a beta ionization chamber connected to a Lindemann electrometer.

Circular shapes required for clinical application are cut out by punching through the lead-rubber backing. Irregular shapes are cut with a scalpel and a rigid guide. Forceps are used to apply the applicator to the lesion, where it is held in place with sticking plaster. The lead rubber acts as backing material during the whole of these operations.

We propose using small red phosphorus-Bakelite applicators activated with P^{32} to irradiate the cornea. These small sources are easy to handle with

forceps, and although they give dosage rates of 5,000–10,000 r/hr, they present little radiation hazard. The dosage rate can be determined in a calibrated electroscope. A special holder, shown in Fig. 9, is used for application to the patient.

• • •

I should like to acknowledge the advice of Professor W. V. Mayneord and Dr. L. F. Lamerton, and the collaboration of Dr. R. J. Walton, Miss H. E. Farran and Dr. H. Blondal. I also wish to acknowledge my indebtedness to many members of the Isotope Division of the Atomic Energy Research Establishment for their invaluable cooperation on many aspects of these problems.

BIBLIOGRAPHY

1. L. H. Gray, *Brit. J. Radiology* **22**, 677 (1949)
2. W. K. Sinclair, S. P. Newbery, *J. Sci. Instr.* **28**, 234 (1951)
3. T. Alper, L. du Preez, *Nature* **164**, 1,001 (1949)
4. N. Veall, *Brit. J. Radiology* **21**, 347 (1948)
5. G. Failla (Private communication via L. F. Lamerton)
6. D. M. Wallace, R. J. Walton, W. K. Sinclair, *Brit. J. Urol.* **21**, 357 (1949)
7. B. V. A. Low-Beer, "Clinical Use of Radioisotopes," p. 309 (C. C. Thomas, Springfield, Ill., 1950)

Method for Determining Relative Dosage of Biological Samples*

Standardized incineration to obtain similar ashed samples is suggested in this method for attaining uniformity in counting samples of biological tissues and liquids. Temperature sensitivity of G-M counters and some problems of self-absorption are also considered

By GUSTAVE JOYET

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In biological studies involving radioactive substances, the absolute number of disintegrations of the samples of tissues, solutions or organic liquids usually need not be known. It is only necessary, rather, to compare the activity of many samples under the same conditions of measurement. In this way, a measurement of *relative dosage* is obtained. The Geiger-Müller counter measures only a fraction of the whole activity of the sample.

To obtain an exact measurement of relative dosage, there are several conditions that should be observed:

The sensitivity of the G-M counter ought to be constant during the measurement of all samples. The geometry and physical conditions must remain constant for the different samples from the point of view of absorption, self-absorption and backscattering. For self-absorption, not only the weight of the sample must be the same, but also the atomic composition.

At this laboratory, the influence of differing conditions on samples formed from solutions, dried tissues, urine,

* Paper presented at the Radioisotopes Techniques Conference, Oxford, England, July 17, 1951.

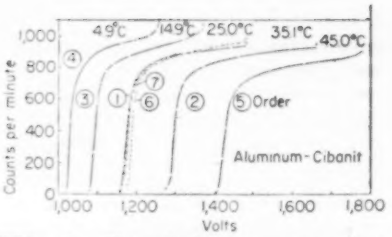

FIG. 1. Characteristic curves of a Geiger-Müller counter affected strongly by temperature change (alcohol-argon filling; pressures: alcohol 2.0 cm, total 10.6 cm)

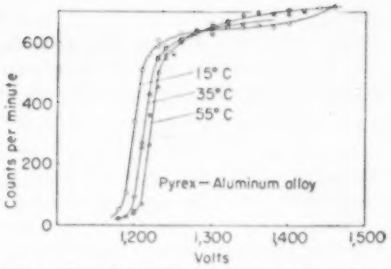

FIG. 2. Characteristic curves of a Geiger-Müller counter affected weakly by temperature change (alcohol-argon filling; pressures: alcohol 2.0 cm, total 10.6 cm)

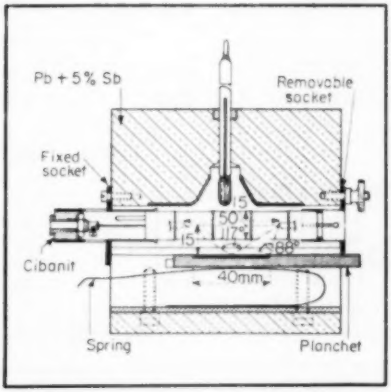

FIG. 3. Apparatus with cylindrical Geiger-Müller counter for studying layers of active ashes

blood, and plasma were studied to test and obtain a uniform method for making relative dosage measurements. The experiments were performed with isotopes that emit hard and soft beta rays.

A first consideration is that G-M counters are always more or less sensitive to temperature. In another paper,* it was pointed out that, with increase in temperature, the characteristic curve of a good counter filled with an alcohol-argon mixture is shifted toward the high voltages, as shown in Fig. 1. From 5° to 45° C, the starting potential shifted from 1,020 to 1,420 volts. The counter used was carefully constructed with cylindrical aluminum walls and was filled with spectroscopically pure argon.

The phenomenon of temperature effect results from an absorption of alcohol by the insulating material at low temperature. This phenomenon is completely reversible. In Fig. 1, the characteristics were taken in the order 1, 2, 3 and so on. At the end of the operations of heating and cooling, we checked 25° C and again found the first characteristic.

If we use not synthetic resin but glass as insulating material, a counter with the same alcohol-argon filling is affected much less by change in temperature. The characteristic curves of a counter with Pyrex glass walls and an aluminum-alloy cathode is shown in Fig. 2. From 15° to 55° C, the shift of the starting potential toward the high voltages is only 20 volts.

We have examined different kinds of counters and have found out that the materials that cause an absorption of alcohol and consequently a temperature sensitivity are Cibanit, picein, polystyrene and apiezon wax. Pyrex glass, aluminum, Anticorodel, and copper, when used with an alcohol-argon filling, are unaffected by temperature or, at best, are affected only slightly.

The temperature effect has nothing to do with the problem of the spurious

* G. Joyet, M. Simon, *Helv. Phys. Acta* **21**, 180 (1948)

TABLE 1

Activity Balance in the Ashing Process with $K^{42}Cl$

(Mice injected intravenously; ashing in several crucibles)

Injected activity			*Recovered activity in the ashes*	
Weight of solution (mg)	*Activity per mg (cpm)*	*Total activity (cpm)*	*Counts per minute*	*%*
Silica Crucibles				
262.4	13.5	3,540	3,325	93.9
			3,311	93.6
			3,300	93.2
			3,425	96.7
406.6	5.11	2,070	1,980	95.6
			1,941	93.7
			2,048	98.8
158.0	9.82	1,550	1,500	96.8
152.6	9.82	1,498	1,350	90.2
			Mean value:	94.7
		(*Mean loss in silica crucibles:* 5%)		
Porcelain Crucibles				
311.7	10.2	3,180	2,549	80.2
229.2	8.61	1,970	1,708	86.8
152.9	9.82	1,325	1,500	88.3
178.8	9.82	1,756	1,513	86.2
			Mean value:	85.4
		(*Mean loss in porcelain crucibles:* 15%)		

counts. The shift of the characteristic curve causes a variation of sensitivity of 1–2% per degree with a good plateau but up to 5% in a counter with a short and bad plateau.

To study the self-absorption and activity of samples consisting of layers of ashes, we constructed an apparatus that supports both the counter and the sample container in a reproducible position.* The profile of this apparatus is shown in Fig. 3. In the center of the cylinder of lead, which is 15 cm in diameter, there is the cylindrical counter with thin aluminum walls, and beneath it the container for the radioactive sample. This container (planchet) is a plate of aluminum alloy with a groove exactly milled with a reamer. The groove (40 × 15 mm and 1 to 2.5 mm deep) contains the active layer. The shielding of lead reduces the background count to 9 counts per minute.

The apparatus with its thermometer is put into a thermostat to prevent a change in temperature and an effect on the sensitivity of the counter. The thermostat maintains the temperature at ±0.2° C two or three degrees above the ambient temperature.

When it is possible to ash tissues without loss of isotope, we use a fast and standardized method of incineration with a rise in temperature up to 700° C.

* G. Joyet, *Helv. Phys. Acta* **20**, 247 (1947)

The technique used for ashing in the electric oven involves a succession of temperatures that are always the same. These temperature successions are given in Fig. 4.

Water of the tissues is first evaporated off between 100° and 120° C. The temperature is raised slowly between 350° and 450° C so as to avoid internal bursting. The maximum temperature is 700° C, and is sustained for a period of thirty minutes. The whole process of ashing lasts two hours and always gives the same atomic composition of the ashes for any one tissue.

In the laboratory at Zürich, this succession of the temperatures is maintained automatically in the electric oven with a diagram of temperature.

For every isotope, it is necessary to determine the loss of activity resulting from ashing of the tissues. Table 1 gives the total loss of activity by mice injected with $K^{42}Cl$. After dissection, the organs are incinerated in separate crucibles. The ashes are then collected for measurement. Thus the total loss, which includes the loss from manipulation of the ashes, is determined.

Table 1 shows that the average loss is 5% with silica crucibles, and 15% with porcelain. Porcelain crucibles, therefore, are not recommended for such use. With iron chloride ($Fe^{59}Cl_3$), the loss is less; on the average it is 2.5% in silica crucibles (Table 2).

Using the same apparatus, we studied the importance of the absorption through the layer of ashes with an isotope that emits hard beta rays, K^{42} ($\beta_1 = 3.65$, $\beta_2 = 2.04$ Mev), and

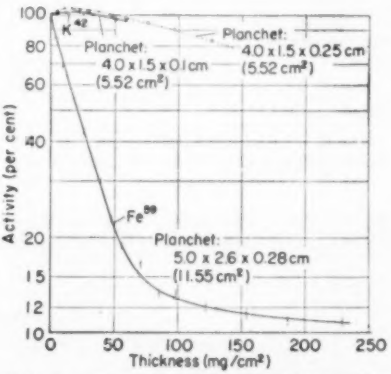
Activity (per cent)
Thickness (mg/cm²)
K42
Fe59
Planchet: 4.0 x 1.5 x 0.1 cm (5.52 cm²)
Planchet: 4.0 x 1.5 x 0.25 cm (5.52 cm²)
Planchet: 5.0 x 2.6 x 0.28 cm (11.55 cm²)

FIG. 5. Curves for K^{42} and Fe^{59} showing absorption by inactive ashes of tissues

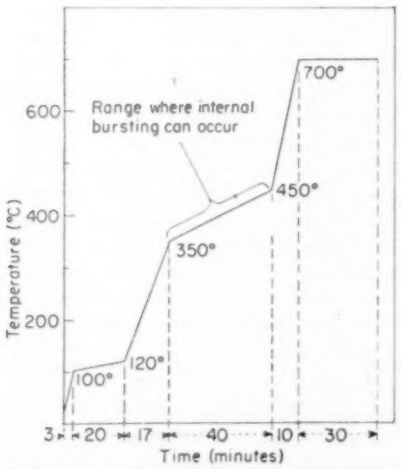

FIG. 4. Diagram of temperatures used in the standardized method of incineration

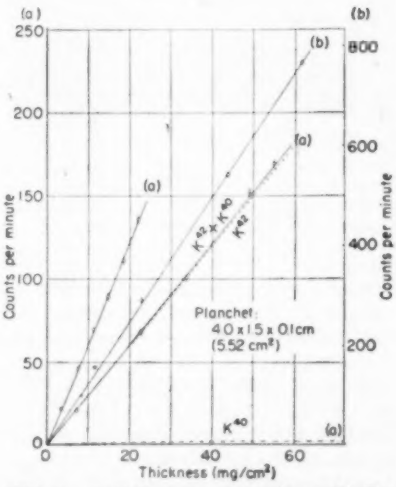

FIG. 6. Activity curves of ashes with K^{42} (hard beta rays)

TABLE 2

Activity Balance in the Ashing Process with $Fe^{59}Cl_3$

(Mice injected intravenously; 1.2 mg of iron per cm^3 of solution)

Injected activity			*Recovered activity in the ashes*	
Weight of solution (mg)	*Activity per mg (cpm)*	*Total activity (cpm)*	*Counts per minute**	*%*
First Series				
118.1	2.22	262	254	96.8
73.4	2.22	163	154	94.6
59.9	2.22	133	126	94.2
Second series				
68.1	2.13	145	146	101.0
90.1	2.13	191	190	99.4
Third series				
111.8	1.61	180	192	107.1
84.4	1.61	135	125	92.2
133.6	1.61	215	209	97.2
			Mean value:	97.8

* Values corrected for absorption differences in the iron of the solution.

TABLE 3

Absorption Data for Different Ashes with Soft Beta Rays of Fe^{59}

	First Series			*Second Series*			
Tissue	μ (cm^2/mg)	$\frac{1-e^{-\mu a}}{\mu}$	ϵ (%)	μ (cm^2/mg)	$\frac{1-e^{-\mu a}}{\mu}$	ϵ (%)	ϵ *Mean of both series* (%)
Bone	0.0299	28.7	−3	0.0276	30.2	−6	−4.5
Tumor spontan.	0.0305	28.3	−4.5	0.0264	31.1	−3.5	−4
Blood	0.0294	29.0	−2	0.0262	31.3	−3	−2.5
Liver	0.0276	30.2	+2	0.0251	32.1	−0.5	+1
Skin	0.0286	29.6	0	0.0248	32.4	+0.5	0
Brain	0.0284	29.7	+0.5	0.0244	32.6	+1	+1
Muscle	0.0289	29.3	−1	0.0242	32.8	+2	+0.5
Spleen	0.0287	29.5	−0.5	0.0238	33.1	+3	+1
Kidney	0.0256	31.8	+7.5	0.0226	34.1	+6	+7
Average	0.0275	29.6		0.0250			

with an isotope that emits soft beta rays, Fe^{59} ($\beta_1 = 0.26$, $\beta_2 = 0.46$ Mev). The thin active layers deposited on the bottom of the container are covered in the apparatus with progressively larger quantities of inactive and homogeneous ashes. These ashes are obtained by incineration of a whole animal with the standardized method of incineration.

Figure 5 gives the absorption curves. With K^{42}, the absorption is nearly negligible (less than 3%) up to 60 mg

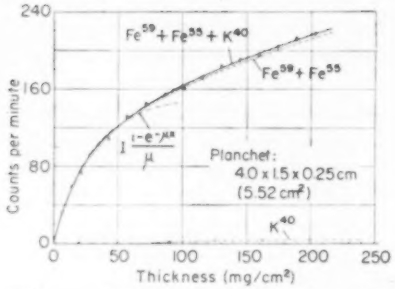

FIG. 7. Activity curves of ashes with Fe^{59} + Fe^{55} (soft beta rays)

of ashes per cm².* With the soft beta rays of Fe^{59}, the absorption is very significant. For the same thickness of 60 mg/cm², the initial activity of the Fe^{59} is reduced to 20%. Self-absorption by the active layer is also significant for soft and very soft beta rays.

Figure 6 gives the activity of different layers of active ashes with K^{42}. As one would expect, these curves are linear up to 60 mg/cm². However, with Fe^{59} + Fe^{55} in the ashes, the activity curve is parabolic, as shown in Fig. 7.

With an isotope, such as potassium, that emits hard beta rays, it is thus possible to make measurements with any quantity of ashes up to 60 mg/cm² because self-absorption is negligible. But with an isotope with soft beta rays, all the samples ought to have exactly the same thickness and be geometrically similar. Only under that condition are their activities comparable. The thickness of the sample should be chosen so that the slope of the activity curve is not too great (100 mg/cm² for Fe^{59}).

Of course, the chemical composition of the ashes of all tissues is not the same. Differences in the amounts of absorption by the different active layers, therefore, should not be considered negligible. We have measured the exponential absorption coefficient, μ,

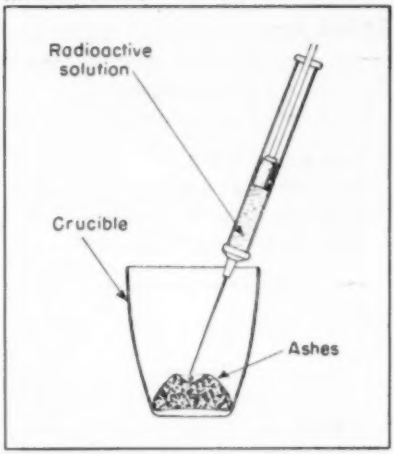

FIG. 8. Preparation of a sample of radioactive solution for activity measurement

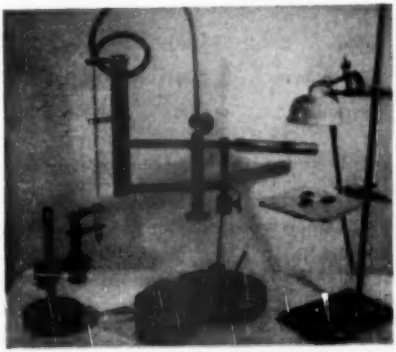

FIG. 9. Equipment for preparing samples of organic liquids: stand with blood sample (left); precision pipetting device (center); container for ashes or charcoal (foreground); and apparatus for drying with infrared rays (right)

for different ashes of bones, blood, liver, etc., for the soft beta rays of Fe^{59}. The measurement was effected with thin layers 1 to 3 mm thick. The values are shown in Table 3. The expression $(1 - e^{-\mu a})/\mu$ is proportional to the measured activity of an active layer of thickness a. The variation in per cent around the average value of this expression is represented by ϵ. We see that for

* The maximum of the curve is caused by Compton electrons from gamma rays of K^{42} that are produced through the layer of ashes.

TABLE 4—

Isotopic Solution	*Injection*
Compound: $K^{42}Cl$ Concentration: 0.30 mg K per cm^3 Reference time: 3d March at 00.00 Activity per mg sol: 54.2 cpm	Injection on 2d March at 10:30 Sacrifice on 2d March at 16:30 Distribution after 6:00 h Injection weight 153.2 mg Injection activity 8,300 cpm

			Radioactivity measurements		
Sample	*Crucible*	*Tissue weight fresh (gm)*	*Counter readings*	*Duration of measurement (min)*	N' *(cpm)*
Suprarenals	...	0.0063	478	30	15.9
Stool	As_1	...	578	30	19.3
Tumor	Bs_2	1.545	8,470	15	565
Urine	Gs_2	...	4,980	15	332
Blood	Bs_2	0.571	2,591	15	173
Musculature	Ds_2	1.763	6,377	16	399
Residue*	Js_2	16.103	10,555	15	704

the two sets of experiments ϵ varies on an average from -5% to $+7\%$. It is necessary to take into consideration such differences when measuring the relative activity of different tissue samples emitting soft beta rays.

Solutions and Organic Liquids

To determine the relative activity of solutions, we do not use the dipping counter or the glass counter with double walls. They need a large quantity of solution and are not easy to clean. Also, their walls are not thin enough.

The relative activity of the solutions is determined in the same manner as the tissue samples. The active solution is withdrawn in a tuberculin syringe, and a small quantity (about 50 mg) is put into a fixed quantity of tissue-ashes or charcoal reduced to powder (Fig. 8). The syringe is weighed before and after the operation so that the weight of the sample is known exactly. The precision obtained by weighing is at least 0.5%. The sample is then evaporated off at a convenient temperature and the ashes carefully mixed before counting starts.

The reproducibility of the method is very good and differences are of the

* Only 280 mg of a total of 954 mg of residue ashes were measured.

† Taking musculature as an example, correction values are derived as follows: The uncorrected measurement, N', is 399 cpm. Since 75 is the corresponding counting loss of the counter, 75 cpm are added to give $N = 474$ cpm. From this, 10.4 for background and 1 for the activity of K^{40} in the ashes are subtracted. The result, 463 cpm, is then divided by 0.95 for a 5 % ashing correction. As the measurement was made 9.21 hours after the reference time, it is divided by a time factor 0.590. The result, 825 cpm (which is 9.95 % of the injected activity), is the relative activity of 1.763 gram of tissue at the reference time. Activity per gram is thus 468 cpm. As activity injected per gram mouse is 8.300/21.6 = 384 cpm/gm, the selectivity of the musculature is 1.22.

‡ Whole blood.

—Measurements and Calculations for Whole Animal Injected with $K^{42}Cl$

Subject	*Experiment No. XXIV*
Mouse ♀ R_3 J 1107 Mammal carcinoma 1.5 cm^3 Aspect: healthy Weight: 21.6 gm	Feeding without K Time of feeding without K: 8 days

Correction of measurements†

Counting loss corr. N (*cpm*)	$N - N_0$ (N_0 = *10.4 background*)	*Corr. for* K^{40}	÷*0.95 for ashing loss*	Δt *for time corr.* h	*Time factor corr.*	*Activity corr. for* t	*Activity per gram of tissue*	*% of injected activity*	*Selectivity*
15.9	5.5	5.5	5.5	−6.01	×0.714	4.13	656	0.05	1.71
19.3	8.9	8.4	8.9	−5.52	×0.720	6.36	...	0.08	...
730	720	719	756	−2.30	×0.870	657	425	7.93	1.11
383	373	373	393	−2.03	×0.890	350	...	4.22	...
185	175	174	183	−1.46	×0.906	166	291	(2.0) 4.46‡	0.76
474	464	463	487	+9.21	÷0.590	825	468	9.95	1.22
(1002)	(992)	(990)	(1041) 3550	+9.37	÷0.582	6100	379	73.5	0.99
							Recovered activity	100.2	

order of 2% only. The containers do not remain active if the quantity of solution for the sample is small.

The relative activities of urine, blood, and plasma are determined in the same way as solutions. The organic liquid is withdrawn in a pipette, put into a fixed quantity of ashes or charcoal, and weighed exactly. The different types of apparatus needed are shown in Fig. 9.

The measurements of the samples are, of course, corrected for counting loss, background, activity of K^{40} in the ashes, and decay of activity with time.

So that the results may be presented clearly, it is recommended that the notion of selectivity of any tissue or organic liquid be introduced. It is

S = (relative activity per gram sample)/(relative average activity injected per gram animal)

The selectivity is independent of the intensity of the activity employed, and independent of the weight of the subject injected. If this method is used, the results obtained by various authors on different animals are thus comparable.

The various calculations and corrections which have to be applied to the raw data are collected in a standardized table for an entire experiment. Table 4 gives an example of the measurements and calculations for a whole animal injected with a solution of $K^{42}Cl$.

It is important to keep the residue of the animal after dissection.

The selectivity of one tissue or organic liquid and the percentage of the injected activity per organ are the two main results of the calculations.

In general, the maximum error of the measurement on any one sample is 5%, and the average error 2.5%. —END

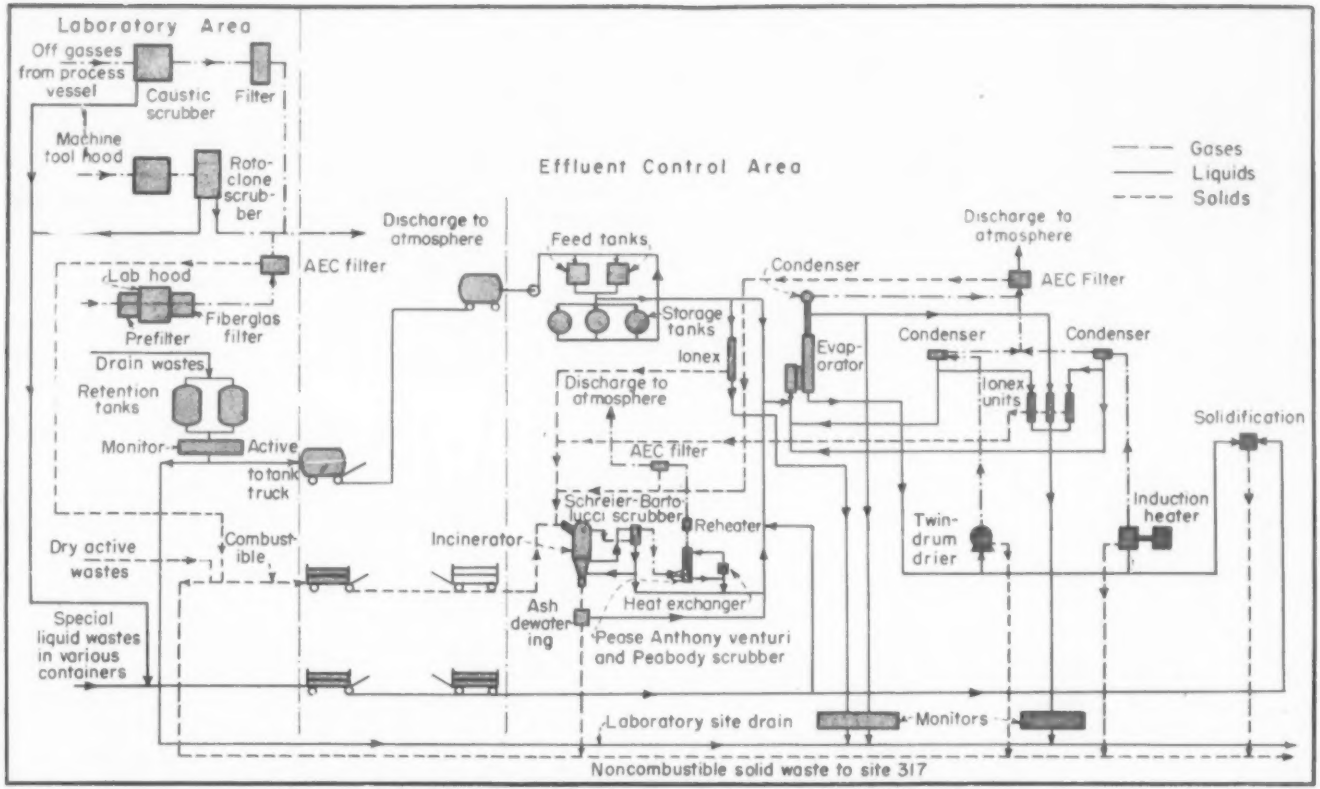

FIG. 1. Flow diagram of waste disposal system at Argonne National Laboratory

A Complete Waste-Disposal System for a Radiochemical Laboratory*

Operation of the system described here for complete control of radioactive effluents will save over $300,000 a year at Argonne National Laboratory. To save this amount each year, equipment costing less than $180,000 was installed

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SINCE THE END of the war, a new policy has been formulated for disposal of radioactive wastes. Ideally, it requires that no radioactivity be discharged back to the environment; at the same time, the bulk of nonradioactive substances used would be returned. Actually, the natural background of radioactivity makes this impossible, and the aim of current processing is to put active wastes into the smallest possible volume consistent with cost and to return to nature, wastes with activities nearly undetectable from the natural background.

Since the wastes encountered are extremely varied, there is no single solution to the problem. And the optimum solution for one laboratory may not even be applicable to another. This article discusses the solutions adopted at Argonne National Laboratory. The problems encountered there are representative of those facing a radiochemical laboratory located in a populous area. The amounts and concentrations of radioactivity are nowhere near as large as those encountered at a production installation, but the types of wastes are much more varied.

In the operation of a laboratory such as Argonne, gaseous, liquid and solid wastes are encountered. The variety of methods used to handle these wastes is indicated by Fig. 1 where they are depicted in flow-sheet form. Each process is described in detail in the following pages.

Gases Are Filtered or Scrubbed

The bulk of the gaseous wastes comes from hood and cave exhausts. Chemical, metallurgical or biological operations involving radioactive materials, as well as operations using hazardous although nonradioactive materials, are done in hoods. The exhaust from such a hood may run from one thousand to several thousand cubic feet per minute. In the chemistry research laboratory building alone, there are about 175 of these hoods.

In the newer laboratories, the air which goes into the hood is conditioned and filtered. Easily accessible at the back of the hood are four Fiberglas prefilters that even out the air flow throughout the hood volume and serve

*Based on a paper presented at the 12th International Congress of Pure and Applied Chemistry, New York, N. Y., Sept. 11, 1951.

as prefilters for both dust and radioactivity, thus lessening the load on the rest of the system. The exhaust gases are conducted through an AEC filter (a highly retentive paper-asbestos filter) before they reach the blower that discharges them through 3-ft stacks on the roof.

So far, these units have operated for eight months in a non-air conditioned building. While the prefilters look very dirty, none have had to be removed because of high pressure drop. Several have been changed because of spills of radioactivity. It has been necessary to change six AEC filters which had been in continuous use 24 hours per day, 7 days per week for 6 months, because of deterioration caused by moisture in the air. Neither the pressure drop nor the radioactivity on these filters was excessive at the time they were replaced. It is necessary that gases passed through these filters be dry or well above their dewpoint, as they are quite sensitive to moisture. When used in this manner, the life of an AEC filter has been estimated as between 6 and 12 months

Machine-tool hoods. Tools used to machine uranium are each individually hooded.* Metal and oxide dusts make up the bulk of the 1,200 ft³/min discharged from each of these machines. These dusts are removed in Rotoclone scrubbers before the gas is discharged. The liquid scrubber waste is trucked to the effluent control area for further processing.

Chemical process vessels. The off gases from vessels in which larger-scale chemical operations are carried out require special treatment. Usually a caustic batch scrubber is used to remove chemical fumes and radioactive gases such as iodine. The scrubbed gas is then conducted into the cell exhaust, filtered, and vented through stacks. Cells in which such operations are carried out are invariably ventilated separately and carried at a negative pressure to the general work areas. The scrubber liquid is periodically trucked to the effluent control area for processing.

Solids Are Incinerated and Stored

A great variety of solid materials become contaminated. Included in recent collections were: filters, paper (absorbent, note, news, filter), wood (benches, flooring, tables, desks, chairs), gloves (rubber, canvas), clothing, shoes, laboratory glassware, ringstands, pipe, fittings, processing equipment of all sizes and shapes, and dead animals (up to goats).

In all areas where activity is present, 7½-gallon cans made of stainless steel and fitted with a foot-operated slide top are provided. Inside each of these dry active waste cans is a cardboard liner. These cans are manufactured by S. Blickman, Inc., Weehawken, N. J.

Two such cans—one for combustible, the other for noncombustible waste—are provided at each location. Any dry active waste may be deposited in these cans if it is small enough and if its activity does not exceed 50 mr/hr. Special containers are provided when requested for bulky or highly active wastes.

A portable stainless-steel collection dolly is used to transport the liners when the containers are emptied; besides scheduled pick-ups, collections are made when requested. Combustible solid waste goes to the effluent control area for incineration. Noncombustible waste is taken directly to the solids storage area.

Storage of solid waste. A storage area known as Facility 317 is provided for retention of solid, noncombustible radioactive waste. It consists of concrete-lined trenches with removable wooden covers and is regularly moni-

* S. S. Gold, *Am. Machinist* **95**, No. 4, 133 (1951)

tored to see that active liquids are not building up. The solid wastes are kept in black iron boxes, 4 × 5 × 6 ft, in the trenches. These bins are of such a size that eventually they may be covered, loaded on railroad cars, and shipped to a national graveyard if one is eventually set up.

This storage space is expensive. It costs about $7.00 a cubic foot. The collection process costs another $5.00 per cubic foot, making the total cost of solid storage almost $12.00 a cubic foot.

Incineration of combustible wastes. This high cost of storage is the reason combustible wastes are segregated. Nearly 80% by volume of the solid wastes are combustible. They are incinerated in the unit shown in Fig. 2. This unit, designed by A. D. Little, Co., Cambridge, Mass., has a burning chamber capable of handling 100 ft³ in an 8-hr day.

The charge is introduced through a chute equipped with interlocked doors to prevent the escape of radioactive gases, and the bags build up on the grates of the furnace. The charge is ignited with gas jets, combustion air being supplied above and below the grates through tuyeres.

During most of the burning period the combustion is self supporting. The gas jets are again used for final ashing. The ash falls through the grates into water and settles down the collection cone through an 8-inch plug valve into a collection drum fitted with an expendable cloth bag filter (Canton canvas). When the drum is full of ash, the valve is closed, a new container is inserted, and the filter bag is used to dewater the ash to sufficient dryness to allow storage in freezing weather.

Combustion gases must, of course, be freed of their radioactivity before discharge. On leaving the furnace, the gases pass first through a Schreier-Bartolucci vane plate washer where the larger pieces of fly ash are scrubbed out

FIG. 2. Incinerator for contaminated combustible wastes

with a water stream that also cools the gases. Water for this scrubbing operation is pumped from the bottom of the furnace to the top of the Schreier-Bartolucci tower and returned from the bottom of the tower to the lower portion of the combustion chamber.

The gases are then passed to a Pease-Anthony Venturi, which was constructed by Chemical Construction Corporation, New York, N. Y. In this apparatus, the high-velocity gas stream is used to disintegrate a water stream admitted at the throat of the venturi.

The resulting intimate mixture of air and water is admitted tangentially to the bottom of a Peabody scrubber constructed by Peabody Engineering Corp., New York, N. Y. In this disengaging section, the gas and the droplets of water that now contain a large fraction

TABLE 1
Decontamination Achieved in Incinerator

Run	Activity of air in* (dpm/m³)	Activity of air in* (Total dpm)	Activity of feed (Total dpm)	Activity of exhaust air (dpm/m³)	Activity of exhaust air (Total dpm)	Beta decontamination factor†
1	195	4×10^5	1×10^7	14	2.8×10^4	3.6×10^2
2	116	2.3×10^5	9×10^7	2	4×10^3	2.2×10^4
3	185	3.7×10^5	3.7×10^9	2.5	5×10^5	7.4×10^5
4	166	4.2×10^5	1.6×10^{11}	4	2×10^6	8×10^7

Operating conditions
Length of run: 4 hr (2½-hr burning time)
Air flow: 500 m³/hr

* Naturally occurring radioactivity in air due to radon-thoron daughters.
† Decontamination factor is total activity of air in and feed divided by the total activity of the exhaust air.

of the smaller dust particles are separated. The gas flows upward through the Peabody tower, passing through fine holes in the scrubbing plates. There the gas is brought into further intimate contact with water or a suitable alkaline scrubbing solution. In the upper portion of the tower, the gas and water are separated by a mechanical baffle system, and the gases then flow to an electric heater located above the scrubbing tower. Sufficient heat is added in this reheater to vaporize any fine mist particles which are still present in the gas and to raise the gas temperature several degrees above the dew point, thus preventing condensation in the remainder of the system.

Both liquid systems must periodically be drained and recharged. The liquid collected is put into the regular effluent-control-building liquid system to be described presently.

The preceding treatment may be enough in most cases of operation to reduce the radioactivity to a permissible level. However, as a final safeguard, the gases are passed through a filter of the AEC type. Such a filter is capable of removing radioactive particles to well within tolerance levels under operating conditions. When replacement is necessary, the loaded filter is burned in the furnace. From the filter the gases are drawn through a positive displacement blower and discharged above the roof.

The incinerator is now on routine operation and is processing the daily accumulation of contaminated combustible wastes. It has been demonstrated capable of a beta decontamination factor of 8×10^7. The data from a series of controlled runs made with known quantities of mixed-fission-product activity are shown in Table 1. The exhaust gas of the unit has always been well below the design specification for the beta air contamination of 2.1×10^5 dpm/m³ and, indeed, has even been lower than the influent combustion air.

This unit is producing about 6 ft³ of ash per 100 ft³ of charge. Even though the installed cost (including engineering) is about $120,000, an operating saving of about $400 per 100 ft³ processed is expected, and the unit should pay for itself in a little over a year. See Table 2.

Liquids Are Complex Problem

The liquid problems and the systems devised to solve them are by far the most complex of all. First, there is a small portion of the liquid waste from

bench-scale, pilot-plant and metallurgical equipment that is usually radioactive. In addition, the drainage from laboratory sinks may be radioactive. Different systems are used for handling each type of waste.

Radioactive liquids. Bench-scale laboratory experiments provide a wide variety of chemical wastes of all concentrations of solids, acids, and radioactivity. The volume of each such waste is individually small (1–10 liters); perhaps 100 gallons per month may be collected throughout the laboratory.

When chemical processes are scaled up to semi-works or pilot-plant size, wastes similar to those just described are produced. The volume is larger (20–200 gallons), the composition is generally more accurately known, and the activity level tends to be higher. Depending on the amount of this type of work underway, 200–2,000 gallons per month of such wastes are produced.

Metallurgical operations (plating, pickling) produce a large volume of liquid wastes containing heavy metals and sometimes normal uranium, both in low concentration. About 50,000 gallons per month of these wastes are produced.

Radioactive wastes are collected in pots of various descriptions that are available to any scientist working with radioactivity in the laboratory. The scientist calls the waste processing group, explains his problem, and is provided with the most suitable container. These containers vary in size, material of construction, and shielding. It is the responsibility of the scientist to try to get all of his activity into the container provided and to supply to the waste processing group complete information as to volume, chemical and radiochemical composition, and concentration of solutions in the container. He is to allow no activity to get into his sink drains, if at all possible. Very often a program of education

TABLE 2
Incinerator Cost Summary

Engineering and Design	$50,000
Equipment Cost	40,000
Installation Cost	30,000
	$120,000

Annual Operating Cost* Basis: 25,500 ft³/year (100 ft³ charged/day)		
Gas 100 ft³/hr		$18.00
Water 13 gal/min		392.00
Electricity		272.00
AEC-filter replacement 1 per 5 days @ $40.00		2,080.00
Labor and Supervision 2 man-hr/hr operator ¼ man-hr/hr supervisor		9,380.00
Depreciation		23,000.00
Maintenance		8,160.00
Overhead		8,160.00
Building amortization		6,900.00
Handling and Storage 6 ft³/day ash stored 1 filter bag/day @ $3.75 Ash handling @ $4.00		12,500.00
		$70,862.00
Cost/ft³		$2.78
Cost/ft³ unprocessed material (collected and stored)		$11.68
Cost/ft³ unprocessed material (delivered to processing area)	$4.79	
Cost/ft³ processed and stored	2.78	7.57
Savings/ft³ by incineration		$4.11
Savings (annual basis)		$105,000.00

* Basis of cost calculations used throughout this paper is:

Steam	$1.00/1,000 lb
Water	0.03/1,000 lb
Electricity	0.0083/kwh
Gas	0.70/1,000 ft³
Labor	2.00/hr
Supervision	2.40/hr
Equipment depreciation	20 %/year of total major equipment cost
Equipment maintenance	100 % direct labor charge
Building amortization	10-year period
Overhead	100 % direct labor charge
Operating year	8 hr/day and 255 days/yr
Liquid storage	1.00/gallon
Solids handling and storage	11.68/ft³
Solids storage alone	6.89/ft³

FIG. 3. Retention tanks for laboratory drain wastes

is necessary to obtain whole-hearted cooperation.

When the containers are collected, each one is treated as an individual problem in deciding what processing its contents shall receive. This is necessary because of the radioactive concentrations involved, and is possible because the volumes are small and the numbers are quite finite.

About 90%, or 900 gallons per month, of this type of waste is processed by feeding small volumes intermittently during the evaporation step of the above-tolerance laboratory drain wastes. But the remaining 10% comes from many sources, and may contain thermally sensitive mixtures; for safety reasons, therefore, this portion will be treated by solidification.

Solidification. In general, the processing procedure will be to neutralize, if necessary, the liquid waste with slaked lime (calcium hydroxide), add and mix Portland cement, and allow the mixture to harden before shipment to the final storage area. The processing will be done in the final storage container in a shielded work area.

Solidification does increase the bulk volume of the waste by 25 to 100%. This increase depends upon the total solids content, since less Portland cement is required when more solids are present. Thus the higher the total solids, the lower will be the increase in volume upon solidification.

Drain wastes. The output of all sinks and drains in working areas where radioactivity is present will be 50,000 gallons per day. These wastes are low in solids content (200–1,000 parts per million) and generally should not contain radioactivity significantly above background. But this waste is treated as suspect because some small amount of radioactivity will get into it even if all precautions are taken.

Consequently, the drains of all laboratory sinks are conducted to retention tanks. These 1,500-gallon glass-lined tanks, shown in Fig. 3, are operated in pairs. When one is full, the flow is diverted to the other and the first is sampled. If the gross (alpha plus beta) activity is less than 10^{-5} $\mu c/cm^3$, the contents are discharged directly to the laboratory-site drain. This drain also carries cooling water known to be free of activity.

The combined discharge then enters the laboratory-site treatment plant, made up of two longitudinal settling tanks having 24-hour detention periods. The *p*H of the wastes are here adjusted whenever necessary. The tanks are so designed that further chemical treatment can be applied if required.

The laboratory-site drain by-passes the sewage plant, but enters the laboratory outfall ahead of the exit monitor where a continuous record of the activity of the discharge is kept for legal purposes. The outfall carries some 400,000 gallons per day of sanitary wastes from the sewage plant; these are admixed with the industrial wastes from the laboratory-site treatment plant. The provisional maximum permissible water contamination of 10^{-7} $\mu c/cm^3$ for either alpha or beta-gamma emitters, suggested by the National Committee on Radiation Protection, will probably be nearly met.

TABLE 3
Typical Analyses of Laboratory Drain Wastes*

Average flow (*gal/hr*)	*pH*	*Solids* (*parts per million*)		*Radioactivity*	
		Total	*Suspended*	*Alpha* ($\mu c/cm^3$)	*Beta* ($\mu c/cm^3$)
16–32	2.2–6.5	530–820	70–200	$0.0–4.6 \times 10^{-8}$	$1.8–7.1 \times 10^{-7}$
27–93	2.9–5.8	650–860	100–180	$1.0–5.7 \times 10^{-7}$	$1.3–8.2 \times 10^{-6}$
18–35	3.5–10.4	1,000–5,600	370	$1.3–4 \times 10^{-7}$	$3.7–6.3 \times 10^{-5}$

* Counted in alpha-beta-gamma proportional counters, model PC-1, manufactured by Nuclear Measurement Corp., Indianapolis, Ind. Alpha yield of 50 %; beta yield, 62 %.

Collection rates, solid content, *p*H, and radioactivity concentrations of typical retention-tank wastes are given in Table 3. It is expected that about 80% of the wastes may be discharged without treatment.

However, if the activity of the retention-tank waste is greater than 10^{-5} $\mu c/cm^3$, the waste is pumped into a tank truck (Fig. 4), brought to the effluent control area, and discharged into the "in-process" holding tankage. There is 36,000 gallons of such tankage.

Wastes requiring processing are drawn from the holding tanks to a primary evaporator where they are concentrated. The overhead is monitored and discharged to the laboratory-site drain or, if necessary, given additional cleanup with an ion-exchange column. The bottoms are fed to one of two drying setups—induction or twin-drum drying—or the solidification process already described. Overheads from the latter stages are put through resin columns or returned to the primary evaporator. Solids are sent to the previously described storage bins.

Primary evaporator. This vertical-tube natural-circulation evaporator, shown in Fig. 5, was constructed by Struthers Wells Corp., Warren, Pa. It has the advantages of adaptability to maintenance, effective three-stage entrainment separation, and ease of operation. The main disadvantage is the possible fouling of the heat-transfer surfaces by scaling and salting.

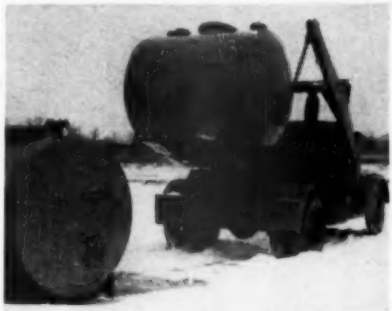

FIG. 4. Tank truck used to transport liquid wastes to processing area

The unit is fabricated of type-316 stainless steel throughout, and is composed of a steam chest, separator chamber, overhead condenser, constant-head feed tank, and control instruments to facilitate operations. The steam chest is 18 in. in diameter and contains 58, 5-foot-long, 1½-inch BWG-16 tubes that provide 106 ft^2 of heat-transfer surface. The vapor and entrained liquid leave the steam chest via a centrifugal separating section and enter the separator. The separator is 20 in. in diameter and 13 ft high, and the entrained liquid is caught in this chamber where natural circulation returns it to the steam chest. The vapor passes through the separator vapor space and is more completely deentrained

FIG. 5. Primary evaporator

by a Centrifix scrubber and reflux if desired. The vapor is then condensed in the triple-pass surface condenser and returned to a 3,300-gallon storage tank for monitoring. The boil-up rate is 150 gallons per hour at 15 lb/in.^{2} gage steam pressure.

This unit has been in routine operation for six months. It has been demonstrated capable of concentrating contaminated liquid waste from 0.08 to 45% by weight of solids. The beta activity of the overheads has never exceeded 7×10^{-7} μc/cm^3 with bottoms of 7×10^{-2} μc/cm^3. A steam economy of 0.85 (pounds condensate/pound steam) has been attained. Operating with an acidic feed, scaling has not been a problem, nor has foaming.

As shown in Table 4, the evaporator cost about $18,000 installed and operates at a cost of $0.08 per gallon processed. It should be noted here that this, and other equipment installed at Argonne, form pilot plant units designed to get information on waste handling, but nevertheless of such size as to allow successful handling of wastes produced during the next two or three years. Cost figures are heavily weighted by amortization because processing rates are low. The figures quoted could be bettered considerably by larger production installations.

Ion exchange. Ion exchange has been recognized for some time as a possible method of removing active ionic impurities from wastes. A program was initiated to determine the feasibility of decontaminating laboratory drain wastes by this method, and further, to compare the cost of ion-exchange decontamination with the cost of evaporation. The regeneration and decontamination of the resin with a minimum volume of regenerant is a critical item. An alternative to regeneration is to burn the resin as combustible waste, a less desirable approach if regeneration is possible.

A two-bed system was set up, with both resins contained in 2-in. internal diameter Pyrex glass pipe. The beds consisted of 0.055 ft^3 of cation resin, nuclear sulfonic-polystyrene type (Nalcite HCR, sodium form), and 0.11 ft^3 of anion resin, quarternary amine type (Nalcite SAR, nitrate form). Both resins were obtained from National Aluminate Corp., Chicago, Ill.

Through this system was passed a filtered laboratory drain waste having a gross alpha and beta activity of about 2.6×10^{-5} μc/cm^3, a *p*H of 2.6 and total solids of 670 parts per million. The flow rate was approximately 1.2 gallons/minute per ft^3 of cation resin.

A total of over 3,000 gallons of filtered drain waste has been decontaminated under the above conditions without regeneration of the resins. This is equivalent to 60,000 gallons per cubic foot of cation resin, or 20,000 gallons per cubic foot of total resin. It was found that while the cation bed became exhausted as far as hardness ions were concerned after 250 gallons were treated, the radioactivity continued to be removed. Analyses of samples taken after passing through the cation bed, and after passing through both beds, have both averaged 3.6×10^{-6} $\mu c/cm^3$, indicating that the anion bed was ineffective. It appeared likely that radioactive anions were not present in large amounts, and that those radioactive ions that were present were not removed to an appreciable extent by the anion bed. Additional evidence for this was the fact that no radioactivity was apparent on the anion bed by G-M meter survey, but the top six inches of the cation bed showed appreciable radioactivity.

To confirm these findings, and to determine the feasibility of decontaminating drain wastes of higher activity, a second system of ion exchange beds, identical to the first, was set up, and filtered drain wastes to which mixed fission products were added to an activity level of 4×10^{-3} $\mu c/cm^3$ were passed through. So far, 900 gallons have been processed through this unit. The effluent activities have averaged about 3.6×10^{-5} $\mu c/cm^3$. It appears that the effluent activity is due to "leakage" rather than exhaustion of the resin. Contrary to the behavior of the first ion-exchange system, the anion bed is removing significant amounts of radioactivity as determined by sampling both columns and by G-M meter surveying of the anion column.

A mixed-bed system is now under construction. This system will be used to determine if it can decontaminate the higher-activity waste more successfully than the two-bed system.

TABLE 4
Evaporator Cost Summary

Equipment Cost	$14,400.00
Installation Cost	3,500.00
	$17,900.00
Annual Operating Cost	
Water 40 gal/min	$1,170.00
Steam 11,750 lb/day	3,000.00
Electricity (feed pump)	20.00
Labor and Supervision	5,300.00
1 man-hr/hr labor	
¼ man-hr/hr supervision	
Maintenance	4,100.00
Depreciation	3,580.00
Overhead	4,100.00
Reagents	200.00
Building amortization	2,000.00
Cost to concentrate 290,000 gallons of 0.08%-by-weight waste to 640 gallons of 45%-by-weight solution	$23,470.00

Cost per gallon of feed processed = $0.081

Basis:
1. Throughput of 1,200 gal/day at a steam economy of 0.85 lb condensate/lb steam used.
2. Operation for 18 days with 1 day of maintenance to produce 48 gallons of 45% by weight of concentrate.
3. No reflux.
4. Steam used on days set aside for maintenance.

On as small a volume scale as this, it may not be economically justifiable to reduce the volume of liquid wastes further. However, there are good health and public relations reasons for avoiding a liquid tank farm here.

Twin-drum drying. This is a standard commercial drying method. The equipment used is shown in Fig. 6; this equipment was manufactured by Guardite Corp., Chicago, Ill. It is a vacuum twin-drum dryer made of stainless steel, the inside having an ASTM No. 4 finish. The rolls have a diameter of 12 in. and are 18 in. long, providing 9 ft^2 of heating area. The machine has a variable splash feed, a

TABLE 5

Twin-Drum-Dryer Cost Summary

Equipment Cost	$20,000
Cost of Installation	1,000
	$21,000
Annual Operating Cost	
Steam 55,000 lb	$55.00
Water 15 gal/min	210.00
Electricity	10.00
Labor and Supervision	2,230.00
Maintenance	1,800.00
Depreciation	4,200.00
Overhead	1,800.00
Packaging, handling and storing	750.00
Building amortization	1,000.00
	$12,055.00
Cost/gal feed material (to twin-drum dryer)	$3.84
Cost/gal original waste (0.08%): (640 × $3.84)/290,000 =	0.0085

Basis:

1. 50 lb/hr of 45% solids feed (specific gravity 1.32) (640 gallons/year—7,000 lb—from evaporator)
2. 60 lb/hr of 20% solids feed (specific gravity 1.15) (2,500 gallons/year—24,000 lb—from miscellaneous sources)
3. 900 hours operating time: 540 hours for 45% solids feed; 360 hours for 20% solids feed
4. Steam economy 0.5 pound overhead/pound steam
5. Dry to 90% solids.

TABLE 6

Induction-Dryer Cost Summary

Equipment Cost	$18,300.00
Installation Cost	2,450.00
	$20,750.00
Aunnal Operating Cost	
Water 10 gal/min	$100.00
Electricity	165.00
Labor and Supervision	2,065.00
1¼ operators/hr	
¼ supervisor/hr	
Maintenance	2,000.00
Depreciation	4,150.00
Handling and storage	770.00
Overhead	1,665.00
Building amortization	1,000.00
	$11,915.00
Cost per gallon of feed material (to induction dryer)	$3.79
Cost/gal original waste (0.08%): (640 × $3.79)/290,000 =	0.0084

Basis:

1. 50 lb/hr of overhead
2. 640 gallons/year of 45% solids feed (specific gravity 1.32) from evaporator
3. 2,500 gallons/year of 20% solids feed (specific gravity 1.15) from miscellaneous sources
4. 670 hours of operating time: 450 hours for 45% solids feed; 220 hours for 20% solids feed
5. Over-all efficiency power in to condensate 30%
6. Dry to 90% solids

variable drum speed, and is operated so that drying is not quite complete to give a nondusting product which drops into a collection pan.

This pilot unit does not provide for remote product removal and therefore cannot be used on high-activity wastes. This installation cost about $21,000; as shown in Table 5, it operates at a cost of $0.01 per gallon of original waste.

Induction drying. A somewhat more radical approach is the induction drying equipment shown in Fig. 7. This equipment was constructed by Eugene Mittelman, Chicago, Ill. The concentrated solution is evaporated by introducing it into a nonconducting container situated inside copper coils to which are fed 25 kw of 27.3-megacycle r-f power through a coaxial cable. The solution boils because of eddy currents set up inside it, and there is no problem of scaling heat-transfer surfaces.

There are two ways of handling the product-removal problem. If a sufficiently cheap plastic can be found which will stand the temperature, the evaporating container can be disposable. Or, the container can be shaped in the form of a truncated inverted cone and the product dried to such a hard cake that

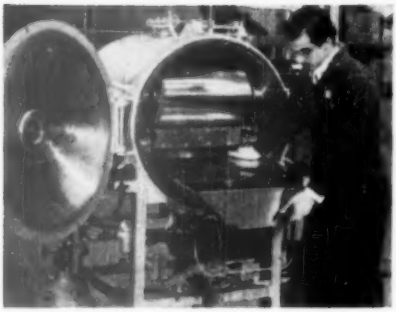

FIG. 6. Twin-drum dryer

FIG. 7. Induction dryer

it will drop out upon inversion of the container. This equipment cost about $21,000 installed and, as shown in Table 6, operates at a cost of $0.01 per gallon of original waste. Since neither drying procedure has as yet been satisfactorily demonstrated, some, if not all, of the concentrates may be reduced to concrete.

Over-all Cost

The calculated cost of complete treatment of a gallon of drain wastes is computed at $0.09, as shown in Table 7. Since storing the unprocessed liquid waste would cost about $1.00 per gallon, assuming a rate of 290,000 gallons per year of dilute drain waste, a gross annual savings of approximately $260,000 may be expected. Against this must be charged the cost of operating the retention-tank system which is estimated at about $60,000 per year, giving a net annual saving of $200,000.

TABLE 7
Over-all Cost Summary

Basis: 290,000 gallons/year; 0.08%-by-weight solid content

Costs per gallon:	
Primary evaporation	$0.081
Drying (induction heating)	0.008
Total	$0.089
Cost of storage (unprocessed)	$1.00
Process cost	.09
Savings	$0.91
Savings:	
Gross annual savings 290,000 × 0.91	= $263,900
Estimated cost of retention tank operation	60,000
Net annual savings	$203,900

The end point of all the processing and the only storage point is the solid storage bins. Liquids sent to the drain are monitored and should be undetectable from background. Whenever a process itself produces a waste (incineration, active condensates from drying, filters), they are recycled to the appropriate place in the process so that the whole is self-contained.

The whole system has not been in operation long enough to provide answers to all the questions, but early indications (as noted) are sufficiently encouraging to allow the belief that a thoroughly practical system for handling the laboratory wastes has been worked out.

* * *

The authors wish to express their appreciation to the following Argonne staff members: A. E. Aikens, Jr., D. C. Hampson, and W. R. Walters; and to O. C. Purdie (assigned to Argonne National Laboratory by E. I. du Pont de Nemours and Co., Inc.) who were responsible for the experimental programs reported here. We also wish to acknowledge the assistance afforded us by the various members of the Graphic Arts Section of this laboratory.

Gamma-Ray Dosimetry with Polyvinyl-Chloride Films*

HCl liberated when a polyvinyl-chloride film is exposed to gammas alters the color of a dye in the film. This system is an effective dosimeter in the range 5×10^5 to 10^7 r

By ERNEST J. HENLEY† and ARTHUR MILLER§

ANY CHEMICAL CHANGE occurring during a photochemical reaction will be some function of the radiation, and may be used as a dosimeter. But before any method can come into common usage several requirements must be met:

1. The system must vary in an exact manner and thus be independent of radiation intensity, wave length, *p*H, oxygen concentration, temperature, etc.
2. The reaction must be irreversible.
3. The results must be reproducible within a few per cent, a very severe limitation since methods thus far reported depend on solvent-solute free radical reactions. Therefore, to eliminate direct action of the radiation on the solute, very low concentrations of reactants are used. Exacting analytical techniques must be employed, and these are difficult to reproduce.
4. The chemical system must be stable under ordinary storage conditions

Possible Dosimeter Systems

Chain reactions give a multiplication factor over the initial chemical change and are very sensitive. This sensitivity is, however, accompanied by decreased reproducibility and stability, and thus the practicability of systems such as H_2O_2, chloral-hydrate, etc., is doubtful.

Reactions in which the ionic yield (number of molecules undergoing change per ion pair formed in solution) is between 0.1 and 10 comprise the majority of radiochemical reactions. The ionic yield, however, is only a rough estimate of the effectiveness of the radiation, since the transfer mechanism is unknown and the role of the excited molecules, which absorb about half the total energy, is unexplained.

The authors know of only two chemical systems that are currently being used for dosimetry. A sodium-benzoate system (*1, 2, 3*) has been used in the Royal Victoria Infirmary, Newcastle, England. The ferrous-ferric reaction has achieved limited popularity in this country. However, the instability of the system, and the difficulty of the analysis, make the results dependent, to a degree, on experimental conditions. Recent work (*4*) also shows that results may differ by as much as 12% with only a ten-fold variation in dose rate.

Dye systems dissolved in agar gels are more qualitative than quantitative radiation measuring devices (*5, 6*).

Photographic plates give integrated dose measurements, allow registration of field geometry, and have some flexibility in shape and size.

The action of radiation upon polyvinyl chloride results in the liberation of HCl, which has been shown capable of altering the color of an acid-base indicator embodied in the film. Work done

* Based on preliminary work conducted by Columbia University, Department of Chemical Engineering, for AEC Contract AT-30-1-1186.

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by Dr. J. Steigman at Brooklyn Polytechnic Institute pointed the way to the application of this reaction to dosimetry (7). If the discoloration could be shown to be proportional to the radiation, a dosimeter combining the advantages of photographic films and chemical systems would become available. This dosimeter would also be economic to produce, easy to analyze, and stable.

Such a dosimeter has been constructed by casting polyvinyl films in which a methyl-violet dye had been distributed. This dosimeter has been used for calibrating Co^{60} and $^{73}Ta^{182}$ sources (estimated at 1 and 2 kilocuries, respectively) at Brookhaven National Laboratory (8).

Fabrication of the Dosimeter

All films cast were 4% solutions of Geon 101 resin in a chlorobenzene solvent. The methyl-violet dye was first dissolved in the chlorobenzene, and then the solution was filtered to remove any undissolved dye particles. The exact dye concentration was therefore not known.

The Geon resin was then added to the solution of dye and chlorobenzene; the mixture was heated to 110° C and held there for an hour to insure complete degassing.

The films were then cast on level, pre-heated glass surfaces and dried for two days at room temperature. The polyvinyl-chloride films thus produced were clear, tough, and uniform.

Next, the films were cut into one-inch squares. Micrometer measurements and transmission readings assured initial conformity in thickness and dye concentration before each irradiation. The films were uniformly 0.0016 in. thick.

Radiation Effects

The effect of radiation on the film was visually detectable; increasing radiation dosage changes the original violet color of the film first to blue and then to yellow orange. For quantitative estimation of the radiation dose, however, spectrophotometric measurements are necessary.

Spectrophotograms of irradiated and unirradiated films were made in both the visible and ultra-violet regions with the Cary double-beam recording spectrophotometer. The most favorable change in the spectrophotometric disposition of the films upon irradiation was the diminution of an absorption maximum at 600 mμ. Subsequently, the analysis of the film was made at this wavelength with the Beckman Model DU quartz spectrophotometer.

Films were cast having initial transmissions of approximately 10, 50, and 83%. To correlate transmission changes induced by radiation in films of so widely varying optical densities, the fraction of the dyestuff converted upon irradiation was calculated from optical data.

If the change in transmission of the film upon irradiation is due to the transformation of the dyestuff, the fraction, x, of dyestuff converted in a film of transmission T,

$$x = \frac{\log T_0 - \log T_\infty}{\log T_0 - \log T}$$

where T_0 is the transmission of the unirradiated film, and T_∞ is the limiting transmission of the film after infinite radiation time (representing complete conversion of the dyestuff).

The saturation transmission was estimated graphically by plotting the per cent transmission against the reciprocal of the radiation dosage, and extrapolating the reciprocal of the radiation dosage to zero. Good agreement was obtained between various series of films having the same initial dye concentrations. The limiting transmission varied from 64.6% for the films having initial transmissions of 8%, to 87.7% for films having initial transmissions of 83.5%;

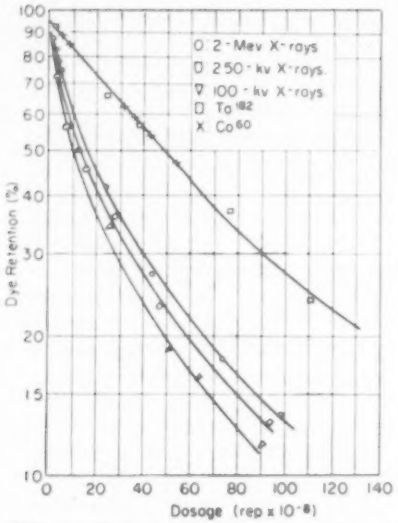

FIG. 1. Curves of dye retention vs dosage

the transmission of a 0.0016-in. film cast without dyestuff was 90.7%.

Absorption Coefficients

Absorption of photons possessing energies greater than 300 kv takes place predominantly by the Compton process. For polyvinyl-chloride films photoelectric absorption accounts for 87% of the energy transfer at 100 kv, for 25% of the transfer at 250 kv and 0% at 600 kv. The Compton recoil processes are, in general, less dependent on photon energies and so greater reproducibility may be expected at shorter wavelengths. On the other hand, with decreasing wavelengths secondary radiations from the film holder and film base become more important.

In calculating the absorption coefficients given in Table 1, several simplifying assumptions were made. The effective wavelength for the X-ray units was approximated by multiplying the peak quantum energy by 0.7, rather than by integrating over the continuous spectrum. For the film, the total photoelectric absorption coefficient, τ, and the Compton scattering coefficient, σ_a, were calculated from the Klein-Nishina equation and the values given by Allen (*9*). The coefficients for air were calculated in the same manner. The dose in roentgens was then multiplied by the ratio μ_{film}/μ_{air} at the particular wavelength to get the dose in rep (μ is the total absorption coefficient).

The effective wavelength for the Ta^{182} gammas was obtained by numerical averaging from the decay scheme presented by Engelkemeir *et al.* (*10*).

Use of the Dosimeter

Previous experiments (*7*) in which methyl violet, in an inert polystyrene base, was irradiated, have shown that the radiation does not act on the dyestuff itself. Therefore, if HCl was liberated in an amount proportional to the radiation dosage, and combined completely with the indicator, the fraction converted should be a linear function of dosage.

It was found, however, that for small dosages the rate of conversion of dyestuff with radiation was first order with the amount of unchanged dye retained in the film (Fig. 1). For larger dosages, the semilogarithmic plot becomes nonlinear, and linearity is approximated on a log-log scale (Fig. 2). Changes in the composition of the polyvinyl-chloride residue become significant after appreciable dosages, and cause deviation from the first-order linearity observed in the semilogarithmic plot.

A slight wavelength dependency was observed with dye concentrations of 0.08% for the three X-radiations used. Each family of curves, however, showed the same shape and characteristics, and thus interpolations for any desired wavelengths are possible.

Table 2 lists the per cent transmissions of films of various initial dye concentrations after exposure to various radiations.

Since the factor for converting roentgens to rep (Table 1) for the Co^{60} and Ta^{182} sources closely approximates the conversion factor for 2-Mev X-rays, these sources were calibrated by direct comparison with the X-rays.

The per cent dye retention (Table 2) for the film irradiated in the tantalum source was plotted on the 2-Mev curve of dye retention vs dosage in Fig. 2. The dosage corresponding to each point (shown as an X on the curve) is recorded in Table 3. This value, when divided by the exposure in hours and

TABLE 1

Absorption Coefficients for Film and Air

Source	*Wave length (A.U.)*	σ_a/ρ (cm^2/gm)	τ/ρ (cm^2/gm)	μ_{film} (cm^{-1})	μ_{air} (cm^{-1})
100-kv X-rays	0.177	0.01723	0.113	0.185	3.89×10^{-5}
250-kv X-rays	0.0707	0.02624	0.0087	0.0497	3.42×10^{-5}
2-Mev X-rays	0.00870	0.02701		0.0383	3.4×10^{-5}
Ta^{182}	0.0205	0.0303	0.0001	0.0431	3.83×10^{-5}
Co^{60}	0.0099	0.0277		0.0393	3.50×10^{-5}

TABLE 2

Transmission of the Polyvinyl-Chloride Film after Exposure to Gamma Rays

Dose (rep × 10^{-3})	*Exposure time (hr)*	*Transmission (%)*
Dye concentration: 0.0125 %		
Source: 250-kv X-rays		
		83.5
0.05		84.1
0.24		84.9
0.58		86.0
1.44		86.9
Dye concentration: 0.08 %		
Source: 2-Mev X-rays		
		51.0
1.72		54.6
4.20		57.1
24.70		67.0
44.00		71.5
74.00		74.5
99.00		76.0
Source: 250-kv X-rays		
		53.5
3.63		60.3
7.25		64.3
14.50		67.1
29.00		69.8
47.00		71.7
94.00		75.9
Source: Ta^{182}		
	0.00	53.5
	2.00	57.5
	11.00	67.3
	17.25	71.0
	34.00	75.8
	49.00	77.6
Source: 100-kv X-rays		
		52.0
1.43		53.5
2.85		56.0
4.30		58.3
13.00		65.4
26.00		70.5
51.00		76.0
64.00		77.0
90.00		79.0
Dye concentration: 0.25 %		
Source: Ta^{182}		
	0.00	10.0
2.28	1.00	12.2
25.00	11.00	20.0
39.00	17.25	23.4
77.50	34.00	33.7
120.00	49.00	42.8
Source: Co^{60}		
	0.00	8.5
	2.16	10.3
	3.50	12.0
	12.89	17.8
	15.25	18.9
	19.50	22.3
	26.40	26.0
	61.00	50.6

TABLE 3
Calibration of the Tantalum Source

Dosage from Fig. 2 (rep)	*Exposure (hr)*	*Intensity (r/hr)*
4.20×10^8	2.00	210,000
25.00×10^8	11.00	203,000
37.50×10^8	17.25	195,000
80.00×10^8	34.00	210,000
	Average:	204,500

TABLE 4
Calibration of the Cobalt Source

Dosage from Fig. 1 (rep)	*Exposure (hr)*	*Intensity (r/hr)*
5.00×10^8	2.16	204,000
8.30×10^8	3.5	210,000
33.00×10^8	12.89	228,000
37.00×10^8	15.25	216,000
44.00×10^8	19.5	200,000
54.00×10^8	27.40	228,000
	Average:	215,000

the roentgen-rep conversion factor, gives the radiation intensity.

The cobalt source was calibrated in the same way. In this case the calibration was against the tantalum source (now calibrated against the 2-Mev X-rays). The dosages are indicated by X's on Fig. 1 and the results are given in Table 4.

The average of the five tantalum calibrations, when divided by the decay factor to correct for time the source had been out of the pile, gave an initial radiation intensity of 400,000 r/hr. The maximum deviation for the calibration is 4.5% and the average deviation is 2.5%, which is well within the error of the spectrophotometric analysis.

The source strength had previously been determined by Victoreen r meters and Adlux photographic film. The r-meter readings ranged from 315,000 to 372,000 r/hr and the photographic film calibrations were between 486,000 and 612,000 r/hr.

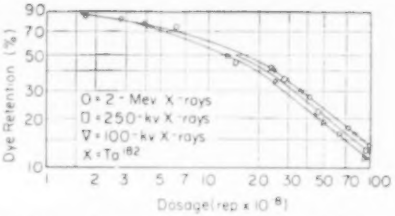

FIG. 2. Curves of dye retention vs dosage

The polyvinyl-chloride-film calibrations thus show the source to be slightly hotter than indicated by the r-meter readings, and considerably weaker than indicated by the photographic film. The greater precision of the polyvinyl films is due in part to the long irradiation periods which made corrections for removal and insertion times unnecessary.

* * *

The authors wish to thank Prof. Elmer L. Gaden Jr. of Columbia University for his help in the preparation of the films and manuscript; Dr. J. Steigman; Mr. B. Wallis, who prepared the films; Dr. H. Burch; Dr. V. Collins and the Dept. of Radiology, Delafield Hospital, for their cooperation and the use of their equipment; Dr. A. Eddman and Mr. S. Bellanca, who conducted the irradiations at Brookhaven; Mr. C. Braestrup, Mrs. I. Knauer, Mr. R. Mooney, and Mrs. F. Slack of the Physics Dept., Delafield Hopsital; and Dr. I. Ruderman of the Physics Dept., Columbia, who reviewed the paper.

BIBLIOGRAPHY

1. M. J. Day, G. Stein, NUCLEONICS **8**, No. 2, 34 (1951)
2. F. T. Farmer, G. Stein, J. Weiss, *J. Chem. Soc.* 3241 (1949)
3. H. Lobel, G. Stein, J. Weiss, *J. Chem. Soc.* 2704 (1950)
4. N. Todd, S. Whitcher, UCLA-34 (1949)
5. M. J. Day, G. Stein, *Nature* **166,** 146 (1950)
6. B. E. Proctor, S. A. Goldblith, NUCLEONICS **7,** No. 2, 83 (1950)
7. A. Miller, B. S. Thesis (Dept. of Chemistry, Brooklyn Polytechnic Institute, Brooklyn, N. Y., 1951)
8. B. Manowitz, NUCLEONICS **9,** No. 2, 10 (1951)
9. D. E. Lea, "Actions of Radiations on Living Cells" p. 345, (Cambridge University Press, Cambridge, England, 1947)
10. D. W. Engelkemeir, M. S. Freedman, J. May, ANL-4473 (1950)

BOOKS

Preparation, Properties, and Technology of Fluorine and Organic Fluoro Compounds (Div. VII, Vol. 1, of National Nuclear Energy Series), Charles Slesser, editor, Stuart R. Schram, associate editor, McGraw-Hill Book Co., Inc., New York, 1951, xxiii + 868 pages ,$10.50.

Because the quantities of fluorine and highly fluorinated organic materials for the gaseous-diffusion program were of a magnitude far beyond any of their pre-1941 applications, a particularly pioneer quality appears in the laboratory investigations and the subsequent or, in some cases, simultaneous plant production of the materials described in this volume.

Unfortunately, at least five years have elapsed since completion of the most recent work summarized by the sixty contributing authors.

Perusal of the forty chapter headings indicates coverage of a wide gamut in the inorganic and organic compounds of fluorine. Large-scale manufacture of fluorine is considered from cell construction and operation, electrolyte composition, and methods of cell operation through to its purification and compression into cylinders. Handling techniques and waste disposal methods, together with the necessary safety and health precautions, are also discussed. Fluorine cells with capacities which range from laboratory scale to 2000 amperes are described; polarization phenomena in these cells together with preventive means is indicated.

The relative merits of packaging by condensation in cylinders at liquid nitrogen temperature as compared to mechanical compression were apparently not resolved. Differences of opinion also exist in the construction of distribution systems; the use of ordinary pipe threads with luting materials and the use of straight threads without pipe dope are recommended by different authors. A caustic scrubber is described for the safe removal of fluorine or hydrogen fluoride.

Syntheses of perfluoro-*n*-heptane and perfluoro-bis-(trifluoromethyl)-cyclohexane and their intermediates by several routes are presented at length in one section of the volume. The preparation of other highly halogenated organic materials is also described. Partial fluorination of chlorinated molecules is accomplished by a replacement of chlorine by the use of inorganic fluorides such as SbF_3. Hydrocarbons (from *n*-butane to medium lubricating oils) or polyfluoropolychlorocarbons have been fluorinated in the vapor phase by the use of CoF_3 and AgF_2.

The preparation of a number of inorganic fluorides and their use as fluorinating agents is discussed. Polymerization of chlorotrifluoroethylene to form liquids and solids is discussed at length. The properties of all these materials are considered in the light of project requirements. Stability of perfluorocarbons as related to small amounts of residual hydrogen in the molecule was investigated. Both laboratory development and industrial application of the reactions are described.

The presentation adopted in some sections is not commensurate with the impressive list of subjects nor is it compatible with the scientific and technological efforts which are reported. Individuals or groups who worked on closely related projects in different laboratories have, perhaps of necessity, reported their work as separate papers. Although unfortunate, unresolved disagreements between such investigations cannot be avoided because of conditions under which much of the original work

(Continued on page 88

CROSS SECTIONS

Improved G-M Counter for Liquid Samples

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Assay of radioactive solutions is easier when the apparatus described here is used. This apparatus was constructed for us by the N. Wood Counter Laboratory, Chicago, Ill. As shown in Fig. 1, it consists of a cylindrical thin-glass-walled G-M tube *A* with a glass jacket *B* sealed to it to form a 1-mm annulus surrounding the counter. The solution to be assayed is poured into cup *C*, and enough solution is added to fill the jacket completely. In any particular counter, the volume of sample is not critical so long as the active counting area of the tube is surrounded.

After measuring the radioactivity with the aid of any suitable scaler or count-rate meter, the counter is drained by opening the stopcock, *E*, and the sample recovered or discarded.

Washing of the counter is accomplished by running distilled water in at *E* and removing the wash water from cups *C* and *D* by means of suction tubes, *F*, connected to an aspirator pump. Since cups *C* and *D* become contaminated when a sample is introduced, they should be allowed to fill and empty 2 or 3 times during the flushing process. Approximately 1 min, or less, is usually sufficient to obtain a normal background count, even after samples of high activity have been measured. Only occasionally is it necessary to employ cleaning solution, etc., to remove adhering radioactivity. In some cases it is advisable to give the counter a preliminary rinse with some solvent other than distilled water, e.g., if the solution being assayed is immiscible in water or contains a solute which is insoluble in water.

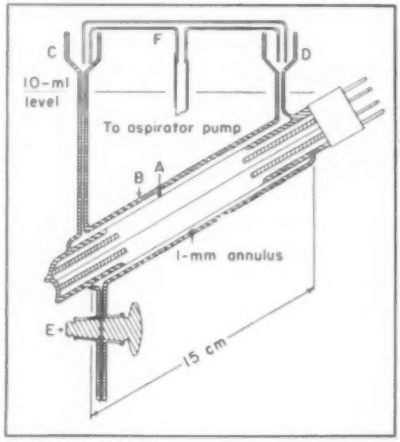

FIG. 1. Counter for assaying the radioactivity in liquid samples

In making the background count, it is important that the jacket be filled with water or other solvent so that any contamination of the counter walls is measured under the same conditions as employed in the assay of radio-

active solutions. Before introducing each new sample, the jacket is drained free of distilled water and then dried by rinsing with acetone and pulling air through it.

Background counts of approximately 100 cpm are obtained, with an average deviation of 15% or less, if reasonable care is taken to rinse out the counter after each sample has been measured. Special lead shielding is ordinarily not required, since the heavy glass jacket excludes all α- and most β-particles. However, because the counter is sensitive to light, the body of the counter must be covered with some opaque material, such as black masking tape.

The sensitivity of the counter to different isotopes is a function of the average energy of the β-particles emitted. As shown in the table on this page, about 17.2% of the Na^{24} and 15.5% of the P^{32} disintegrations are detectable as counts in the liquid counter, whereas the corresponding values for the weaker β-emitters, Au^{198} and I^{131}, are only 4.3% and 1.5%, respectively. If maximum counting efficiency is required, and particularly if weak β-particles are to be assayed, the thin-window and windowless counters have a distinct advantage over the liquid counter which has a minimum wall thickness of about 30 mg/cm² at the sensitive portion of the tube. However, the total volume of solution that can be assayed conveniently is about 10 times greater with the liquid counter than when the sample is counted wet or dry in a typical counting crucible.

Results may be expressed in μc/ml by taking the product of the observed counting rate, the dilution, and the multiplicity factor, and dividing by the number of disintegrations per minute per microcurie of isotope (222×10^4). The multiplicity factor must be determined for each counter by counting a solution of known isotope concentration. In this manner, the following multiplicity factors were found for one of our counters: 0.58 for Na^{24}, 0.66 for P^{32}, 2.3 for Au^{198}, and 6.6 for I^{131}.

Since the volume of solution and its position in relation to the G-M tube is fixed in this type of counter, the geom-

Sensitivity of Counter to Various Isotopes

Isotope	Radiation energy (Mev) β	Radiation energy (Mev) γ	Per cent of disintegrations counted
Na^{24}	1.39	1.38 2.76	17.2
P^{32}	1.71		15.5
Au^{198}	0.97	0.41	4.3
I^{131}	0.6 0.315	0.37 0.638 0.283 0.080	1.5

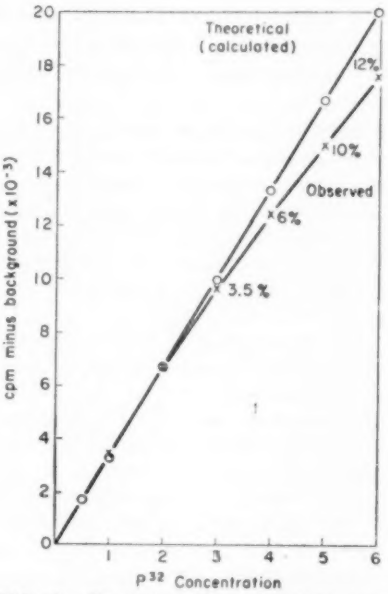

FIG. 2. Deviation from direct proportionality in counting P^{32} solutions in liquid counter

etry of counting does not vary. The resolving time of the counter permits counting rates of up to about 7,000 cpm before deviations from direct proportionality in counting become significant, but as the counting rate exceeds this value a suitable correction must be made. As shown in Fig. 2, this correction amounts to approximately 3.5% at 10,000 cpm, and progressively increases to about 12% at 20,000 cpm.

Calibration Checking Device for Ion-Chamber Meters

By S. A. Kingsbury

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A device has been developed that permits a rapid accurate check on the calibration of radiation survey instruments to be made without the use of radium standards. This device can be constructed of readily available materials at low cost, and can be operated by nontechnical personnel. Essentially, it consists of a sealed beta source (Sr^{90} in equilibrium with Y^{90}) mounted inside the ionization chamber of an instrument. An externally mounted rotary switch, shown in Figs. 1 and 2, places the source in an unshielded position inside the chamber for calibration checking, or rotates it to a shielded position for survey work.

The optimum beta-source strength and number of sources needed to check the calibration of a particular instrument depends upon the range of the instrument and the calibration adjustments. It is usually desirable to set the calibration of a survey instrument at the upper part of the instrument range, thereby insuring operation over the entire range and more nearly accurate readings at high radiation levels. The strength of beta source necessary to produce a desired meter deflection can be determined by inserting a trial source, containing a known amount of beta-emitting material, into the ionization chamber. The meter deflection thus obtained can serve as a guide in estimating the amount of this material needed for the permanent source.

In operation, survey instruments with an internal beta standard are initially calibrated against a radium standard. Immediately following such

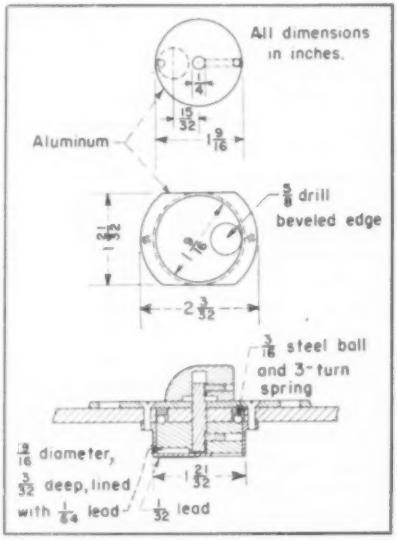

FIG. 1. Details of calibration device

a calibration, a calibration check point can be established by exposing the internal beta source to the ionization chamber and noting the meter deflection obtained. Subsequent readings will indicate any appreciable change in instrument sensitivity. If a change in sensitivity is noted, a reasonably accurate recalibration can be made by adjusting the instrument to read at the calibration check-point value.

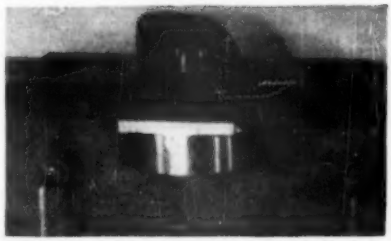

FIG. 2. Calibration device installed in ion chamber of survey meter

Effect of Ionizing Radiations on Vitamin B_{12}

By P. C. Markakis,* S. A. Goldblith, and B. E. Proctor

Department of Food Technology, Massachusetts Institute of Technology Cambridge, Massachusetts

In connection with the general research program in this laboratory on effects of high-energy electrons on foods and their components, experiments were conducted to study the effect of such radiations on vitamin B_{12} in pure solution and in raw whole milk. A Van de Graaff accelerator producing 3-Mev electrons was used as the source of ionizing radiation (*1*). Samples of crystalline vitamin B_{12} (Merck) in distilled water and in raw milk were irradiated in small glass ampules. The vitamin concentration in the samples was determined microbiologically according to Oser's method as described by Winsten and Eigen (*2*). The basal medium used was that of Winsten and Eigen, and the test organism was *Lactobacillus leichmannii* 313 (ATCC 7830).

In the case of the pure solution of vitamin B_{12}, the retention of the vitamin after radiation doses of 2,500, 4,500, 8,100, and 14,600 rep was, respectively, 68, 52, 35, and 21% when the initial concentration was 10 μg/ml and 77, 67, 52, and 32% when the initial concentration was 15 μg/ml. The inactivation dose D_0 for these two concentrations averaged 7,630 and 11,505 rep, respectively. This was calculated according to the formula given by Lea (*3*), $\ln n/n_0 = -D/D_0$, where n_0 is the initial number of organisms, n the number that survived a dose D, and D_0 is the dose required to score an average of one hit per organism. The average specific inactivation doses, D_0/C, were 7.63×10^3 and 7.67×10^3 rep/gm/ml.

With vitamin B_{12} in raw whole milk in an initial concentration of 0.0049 μg/ml, the retention of the vitamin after radiation doses of 50,000, 100,000, 250,000, and 500,000 rep was, respectively, 100, 75, 67, and 69%.

These data show that vitamin B_{12} in pure solution is relatively radiosensitive, even more than ascorbic acid (*4*).

The constancy in the specific inactivation doses in the case of the pure solutions of the vitamin shows that the effect of the radiation was

(*Continued on page 82*)

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NUCLEONIC EVENTS

JOINT CONGRESSIONAL COMMITTEE CALLS FOR MORE "TECHNICAL DARING" IN THE ATOMIC-ENERGY PROGRAM

Fulfilling its statutory duty to report to Congress on its "continuing studies of the activities of the Atomic Energy Commission" and related problems, the Joint Congressional Committee on Atomic Energy headed by Senator Brien McMahon last month released the text of its latest report to Congress in which it indicated that "more scientific and technical daring should be brought to bear" upon this nation's nuclear development program.

Significant points made by the Committee on particular aspects of the program are given below in excerpts from the report.

On legislation. Among "the unusual aspects" of its work, the report said, is the fact that, thus far, the Joint Committee "has found only one major amendment to the original . . . law to be necessary."* Its activities "have mainly consisted in a constant scrutiny of the unfolding atomic enterprise."

On raw materials. "From its earliest days," the Committee reported, it "has placed heavy emphasis upon raw materials problems. It attempted to encourage the discovery and development of new uranium sources, particularly on the North American continent, but overseas as well. Committee members played an active role in the international arrangements, effective by early 1948, that produced desirable results regarding uranium imports from abroad. Likewise the Committee urged speed not only in the conclusion of raw materials agreements with such countries as South Africa but also in the construction of certain domestic plants which make possible a more efficient use of uranium. Moreover, the Committee itself called attention to one significant source within the United States that was not being adequately exploited.

"The Raw Materials Subcommittee, under the Chairmanship of Senator Anderson, is conducting a series of hearings and inquiries which have already demonstrated that the uranium situation has substantially improved and promises to improve still further.

"Committee members have emphasized their finding that, within broad limits, the United States may obtain as much uranium as it desires for defense purposes provided that the cost is deemed to be worth while. Much has been accomplished by way of eliminating the widespread but faulty assumption that uranium ore receipts must be a rigidly fixed quantity, and establishing as fact that supplies will vary with the amount of money, manpower, and effort directed toward obtaining them.

"The Committee . . . recommends still further intensification of this effort, looking toward increased use of thorium as well as uranium."

On production "The past half decade," the report said, "has seen

* EDITOR'S NOTE: The reference here is to the amendment permitting the government to exchange certain atomic information with friendly countries (NU, Nov. '51, p. 68). President Truman signed this legislation on October 30.

advances and the opening of new possibilities in techniques of producing fissionable and fusionable materials. The over-all picture, which once involved the danger of major set-backs, has brightened. . . . The Commission has raised production levels to an all-time high."

"In several instances, the Committee saw opportunities to step up plutonium production, rapidly and at minimum cost, and it exerted continuous pressure resulting in seizure of these opportunities. Another problem which has occupied considerable Committee time is the ratio between plutonium and U-235 output; for a healthy balance between the two is essential to national security.

"Still another problem at the forefront in Committee deliberations is that of AEC relations with contractors, especially two aspects: (1) The desirability of awarding contracts to as many large and small private firms as feasible, rather than concentrating the work among a few big companies; and (2) the desirability of awarding as many contracts as feasible through competitive bidding and on a lump-sum or unit-price basis, rather than through negotiation and on the basis of cost-plus-fixed-fee. More progress has been made in the first of these two aspects than in the second. In its last general report to the Congress, two years ago, the Committee said the following:

> Only a lump-sum, unit-price, or similar-type contract, offering maximum opportunities for profit, creates highest incentive to keep down costs. This system has been applied successfully in the case of certain feed material processes; but whether it might work at Oak Ridge, Hanford, and Los Alamos is a difficult question which the Commission must face at some time in the future.

Greater effort is recommended toward extending the use of lump-sum or unit-price contracts.

"However, where cost-plus-fixed-fee contracts today prevail, the Committee is glad to observe an increase in cost consciousness and fiscal controls without impairing rapid progress. One facility, for example, was recently completed three months ahead of schedule and at a cost nearly three million dollars less than anticipated. However, throughout the project, in varying degrees, there remains room for improvement."

On reactor development. This subject was introduced in the present report by reference to the previous JCC report, as follows: "In its 1949 report, the Committee said it—

> believes that reactor development should proceed with all possible speed, and disappointment therefore follows from reflection that, in 2½ years, the Commission has not broken ground on a single new-type high-power reactor.

The Committee added this comment:

> Results are what count; and by that standard the rate of progress in reactor development for military purposes is overslow, notwithstanding the many good reasons which account for it. The Committee urges every possible effort in this field.

Since these words were written, genuine gains have been made. Reactor production capacity at Hanford has increased; the research reactor at Brookhaven, after many vicissitudes and avoidable delays, started operating; the reactors planned for Savannah River are under way; the important Materials Testing Reactor and a land-based prototype of a submarine reactor are well along toward realization at Arco, Idaho; and the Experimental Breeder Reactor, also located at Arco, 'went critical' a few weeks ago."

"The Reactor Development Subcommittee . . . has helped concentrate the reactor program upon specific priority objectives, reducing the earlier tendency to study much but to undertake little which is concrete. As regards one vital reactor project, the Subcommittee concluded that a major policy decision had been too long delayed and that additional delay might seriously hamper progress. The Subcommittee therefore informed the appropriate civilian and military authorities that, unless the necessary decision were reached within a specific time period, they would be

REPRINTS of . . .

Civil Defense and Buyers' Guide

A limited number of reprints of this special section from the November, 1951, NUCLEONICS are available at $1 per copy. The reprint includes both technical data for civil defense and the annual buyers' guide to equipment used in the nucleonics field. To purchase, send cash with order to: Editorial Department, NUCLEONICS, 330 West 42d Street, New York 18, N. Y.

requested to appear and explain their reasons for deferring judgment. The decision (one which the Subcommittee itself endorsed) was made on the next-to-last day of the stipulated time period."

"The Subcommittee has been most pleased with the drive and the business-like methods brought to bear upon the submarine prototype reactor now under construction at Arco. . . . The Subcommittee has been least pleased with progress at Schenectady, New York. The 1949 Committee report pointed out that after three years this laboratory had yet to start building a reactor. The same remains true today, two years later.

"The Committee is keenly interested in the current study program involving eight private industrial firms. These are exploring the possibility of offering to build reactors wholly or partly at their own expense, with the dual purpose of producing power for sale to the public and plutonium for sale to the government. It is recommended that the complex factors entering into such a possibility be brought rapidly to a point of crystallization, so that they may be properly evaluated and judged.

"The Committee also renews its 1949 recommendation, particularly as regards thorium breeders and plutonium production reactors of the future, that 'reactor development . . . proceed with all possible speed.'"

On weapons. Among other comments on this subject, the Committee "specifically suggests that early consideration be given to the possibility of a second weapons development laboratory to supplement Los Alamos at least in certain engineering phases." It adds that if "any one area of atomic endeavor were to be singled out as having yielded the most far-reaching progress over the past two years, it is the area of weapons development."

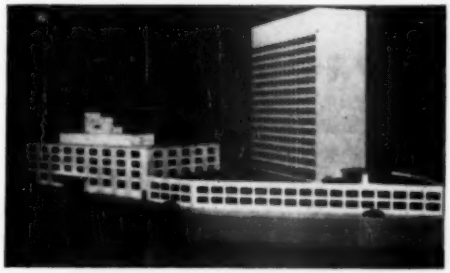
Conclusions. The AEC, the Committee concludes, "after almost five years of operation, is making progress at a faster rate than in its earlier days. . . . On the other hand, as this report indicates, there are areas in our atomic program which need to be shored up, and there are opportunities for faster advancement which need to be vigorously exploited. If the Committee has a single general comment to offer, it is this: Greater boldness and more scientific and technical daring should be brought to bear upon the program."

SCINTILLATION COUNTERS TO BE DISCUSSED AT SYMPOSIUM

A Symposium on Scintillation Counters will be held at the National Bureau of Standards, Washington, D. C., on January 29–30, 1952. The program includes papers on photomultipliers and multiplier performance, liquid and crystal phosphors, time resolution, and associated electronic equipment.

Attendance at the meetings, which are under the joint sponsorship of the American Institute of Electrical Engineers, the Institute of Radio Engineers, the Atomic Energy Commission, and the National Bureau of Standards, will be limited.

Those desiring invitations may communicate with R. S. Johnson, Radiation Instruments Branch, U. S. Atomic Energy Commission, Washington 25, D. C.



Columbia University last month announced plans to construct a $22-million dollar Engineering Center at 125th Street and Riverside Drive in New York and showed the model of the center pictured here. Calling it a "notable new design in engineering education," John R. Dunning, dean of the Engineering School, who made the announcement, said the Center is expected to be ready by Columbia's Bicentennial Anniversary in 1954. In addition to housing the Engineering School, plans include the creation of two new teaching and research units, the Institute of Advanced Science and the Division of Cooperative Research in Engineering. A fund-raising campaign for the Center has gotten under way; $13,650,000 is being sought immediately for buildings and equipment, and $8,500,000 will be required subsequently for teaching and endowments. The center will accommodate 1,750 students

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T. H. JOHNSON TO HEAD AEC RESEARCH DIVISION

The Atomic Energy Commission recently announced the appointment of Thomas H. Johnson as director of the Commission's Research Division. Dr. Johnson comes to the AEC from Brookhaven National Laboratory, where he served as chairman of the physics department. He replaces Kenneth S. Pitzer who resigned in June to become dean of the University of California's College of Chemistry.

INSTRUMENTATION CONFERENCE PLANS ANNOUNCED BY AIEE

The Fourth Annual Conference on Electronic Instrumentation in Nucleonics and Medicine, sponsored by the American Institute of Electrical Engineers, will be held at the Hotel Commodore, New York, January 7–8.

The opening session which begins at 9:30 a.m. on January 7, will be presided over by G. Failla of Columbia University. The papers to be presented at this session include: *The combination of phosphors and phototubes as a precise radiation detector*, by Walter S. Lusby, Westinghouse Electric Corporation; *A unique instrument for the precise measurement of gamma radiation*, by Philip E. Ohmart, Ohmart Corporation, *Fluorescent crystal counting in medical tracer research*, by Hal O. Anger, University of California; *A cobalt-60 irradiator for teletherapy*, by E. Dale Trout and John Vlach, General Electric Company; and *Scintillation counting for brain tumor localization*, by Bertram Selverstone, Tufts College Medical School, and W. S. Macdonald and W. Eustis, W. S. Macdonald Co.

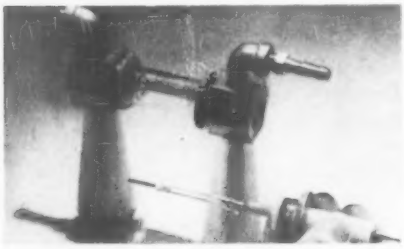
H. D. Moreland of the Westinghouse Electric Corporation will serve as chairman for the afternoon session on January 7, starting at 2 p.m. The papers scheduled at that time include: *Calorimetric determination of the energy of X-ray beams*, by John H. Laughlin, University of Illinois College of Medicine; *High-energy electron and X-ray beams from the 80-Mev synchrotron*, by H. C. Pollack, General Electric Company; *Production of monochromatic X-radiation for microradiography by excitation of fluorescent characteristic radiation*, by T. H. Rogers, Machlett Laboratories, Inc., *X-ray image bright-*

(Continued on page 94)

PRODUCTS and MATERIALS

CALIBRATOR

Rutherford Electronics Co., 3707 S. Robertson Blvd., Culver City, Calif. The model D-2 calibrator is designed for accurate generation of pulse trains. Seventeen different pulse rates with spacings ranging from 10 to 200,000 μsec are available at the output connections. Coincidence circuits are employed to make negligible the phase lags between the various outputs.

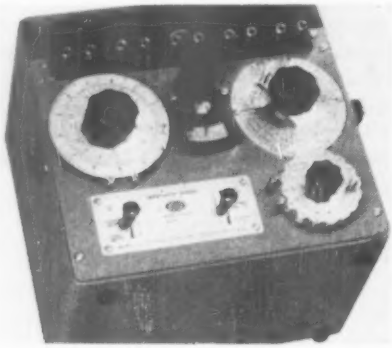


HIGH-INTENSITY LIGHT

Huggins Laboratories, 790 Hamilton Ave., Menlo Park, Calif. This water-jacketed mercury arc lamp has a brilliance range of 40,000–90,000 candles/cm² and a light output range of 65,000–130,000 lumens. Operation can be from a-c, d-c, single-flash, or stroboscopic power supplies. All-quartz accessories can be obtained if a source of ultraviolet light is desired. Arc widths of 1, 1¼, and 1½ mm are available.

DESICCATOR

Bethlehem Apparatus Co., Inc., Front and Depot Sts., Hellertown, Pa. This desiccator, known as the Dri-Jar, will accommodate from two No. 3 crucibles up to 24 No. 0000 crucibles at one time; it can also be used for other types of samples up to 3 × 5½ in. in size. Hot or cold crucibles may be stored; liquid or dry desiccant may be used. The jar is 3½ in. in diameter and 6⅝ in. high.



IMPEDANCE BRIDGE

Brown Electro-Measurement Corp., 4635 S. E. Hawthorne Blvd., Portland 15, Ore. The model 250-C impedance bridge is designed to make measurements over the following ranges: resistance, 1 milliohm to 11 megohms; capacitance, 1 μμf to 1,100 μf; inductance, 1 μh to 1,100 henrys; Q-factor of inductances, 0.02 to 1,000; and dissipa-

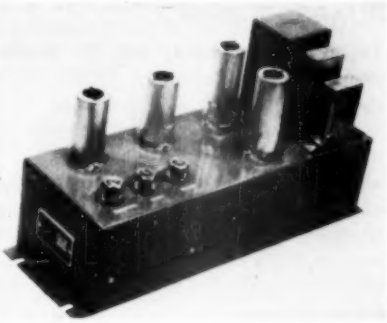
tion factor of capacitors 0.001 to 1.0. Precision reference standards, 1,000-cycle-tone generator, sensitive galvanometer, and replaceable flashlight cells to power the bridge are included in this portable device. The bridge can be converted to 115-volt, a-c, operation by inserting the model 855-A amplifier-oscillator into the battery compartment. This provides a highly stable oscillator and a high-gain null amplifier, with plug-in frequency selection and a visual null indicator. With this unit a balance precision of 0.02% is possible on most measurements of capacitance and inductance, it is claimed.

POWER SUPPLY

Kepco Laboratories, Inc., 149-14 41st Ave., Flushing, N. Y. Continuously variable voltage in the range 0–1,000 volts, 0–50 ma, is available from the model 1020 regulated power supply. In the range 100–1,000 volts the variation is said to be less than 0.1%; in the range 30–100 volts it is less than 0.5% Ripple is said to be less than 10 mv. A 6.3-volt, 10-ampere, a-c output is also included.

LINE-VOLTAGE REGULATOR

Sorensen and Co., Inc., 375 Fairfield Ave., Stamford, Conn. The model 1001 regulator is said to maintain a regulation of ±0.01% over a load range of 1–1,000 volt-amperes. Input is 95–130 volts, a-c, single phase, 55–65 cycles; output voltage is adjustable from 110 to 120 volts, a-c. The accuracy is guaranteed at room temperature, for a resistive load, an input variation of ±10%, and over a 2-to-1 load change.



SERVO AMPLIFIERS

Industrial Control Co., Wyandanch, N. Y. The models 421-A and 423-A 400-cycle servo amplifiers are designed to drive two-phase servo motors requiring 6 and 9 watts per phase, respectively. Maximum gain of the amplifiers is 1,000; phase is adjustable through 160°; internal pickup is below 2 mv. Screw-driver controls for damping, gain, and carrier phase are independent of one another. Plate and filament power can be supplied by any power supply, with no regulation, filtering, or additional bias sources necessary for operation.

VIDEO AMPLIFIER

Polarad Electronics Corp., 100 Metropolitan Ave., Brooklyn 11, N. Y. The Model V-2 wide-band video amplifier has a flat amplitude response (±1 db) from below 10 cps to 20×10^6 cps, it is claimed. The instrument is designed for use as an oscilloscope deflection

amplifier for the measurement and viewing of pulses of extremely short duration and rise time. It can be used to extend the amplitude range of vacuum-tube voltmeters and signal generators. According to the manufacturer, 60 cycle square waves are passed with less than 5% tilt.

FILM-BADGE SERVICE

Technical Associates, 140 W. Providencia Ave., Burbank, Calif. This service provides and monitors film badges worn by personnel exposed to radiation. New badges are furnished weekly, and a weekly report of the examination of the exposed badges is provided. Wrist badge holders and film rings are also available for applications in which the hand may receive excess exposure.

FORCE CONTROL

Fluid Controls Co., Inc., 5150 Ridge Ave., Philadelphia 28, Pa. This device converts a variable force or weight into an easily measured pneumatic signal. It is useful for either batch weighing or continuous process control. The instrument will indicate, record, or control weight or force through standard instruments. Net weight can be indicated directly. The mechanism is said to be completely free from lost motion; total movement is restricted to $\frac{1}{8}$ in.

NEW COMPANY

The Ohmart Corp., Cincinnati, Ohio, has been formed to manufacture a line of instruments for measurement of gamma activity. The instruments will operate by producing an electric current directly from radioactivity, and no high-voltage power supplies will be necessary for operation.

LITERATURE AVAILABLE

Radioisotope laboratory. Brochure shows laboratory installed in hospital. *S. Blickman, Inc., 2506 Gregory Ave., Weehawken, N. J.*

Tube fittings. Catalog B-151 describes Swagelok tube fittings. *Crawford Fitting Co., 884 E. 140th St., Cleveland 10, Ohio.*

Small motors. Pamphlet discusses applications and selection of subfractional-horse-power motors. *Air Marine Motors Inc., 2183 Jackson Ave., Seaford, N. Y.*

Plastic products. Circular describes polyethylene fittings and containers. *American Agile Corp., Plastics Division, 5806 Hough Ave., Cleveland 3, Ohio.*

Oscillograph. Bulletin gives specifications of a high-speed, direct writing oscillograph. *Offner Electronics Inc., 5320 N. Kedzie Ave., Chicago 25, Ill.*

Laboratory equipment. Catalog describes fixed and movable laboratory equipment. *Atomic Instrument Co., 84 Massachusetts Ave., Cambridge 39, Mass.*

Nickel tubing. Technical Bulletin T-17 gives data on nickel and nickel alloy pipe and tubing. *Technical Service Section, International Nickel Co., Inc., Development and Research Division, 67 Wall St., New York 5, N. Y.*

Recording oscillograph. Bulletin CEC-1500B describes recording oscillograph and accessories. *Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 8, Calif.*

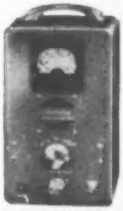
Variable speed drive. Technical data sheet No. 4C describes miniature variable-ratio speed changer. *Metron Instrument Co., 432 Lincoln St., Denver 9, Colo.*

Automatic controls. Bulletin G-1 shows line of automatic contact meter-relay controls. *Assembly Products, Inc., Main at Bell Sts. Chagrin Falls, 1 Ohio.*

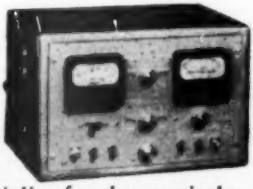
For Your Nuclear Laboratory

BASIC SCALER Model 100 was designed for the express purpose of providing an easy-to-operate scaling circuit of the *finest quality* at *minimum cost*, and in such form that additional facilities could be added from time to time to meet the increasing requirements of the user. In one compact unit this instrument combines a *direct reading electronic scale of 100*, mechanical register for *extended range* and a *regulated high voltage power supply*. An *accessory socket* permits full use of such auxiliary equipment as automatic clock, predetermined timers, extended range unit for predetermined count, loud speaker, count rate meter and count rate computer. Dimensions: 14½" x 9¾" x 10¾". Wt. 18 lbs.

UTILITY SCALER Model 110 includes all of the features of the Model 100 plus additional facilities which make it a universal laboratory instrument for nuclear work. The power supply can, by simple adjustment, be made to provide either *positive* or *negative high voltage*, thus making it suitable for use with either *Greiger Muller or Scintillation detectors*. A built-in preset-count mechanism provides scaling factors of 100, 200 and 400 and *automatic predetermined counts* of 1000, 2000, 4000, 10,000 and 20,000. *Accessory plug* and convenience outlet at the rear chassis of the Scaler which provide for unit, counting rate computer, preamplifier and other auxiliary devices. Dimensions: 14½" x 9¾" x 10¾". Weight: 18 lbs.



LABORATORY MONITOR Model 1800 is a general purpose count rate meter with provision for *visual and aural indication*. Panel switch permits selection of five different meter ranges (300 cpm., 900 cpm., 3000 cpm., 30,000 cpm.) Meter is *self zeroing* and does not require calibration. A single control is provided for "On-Off" and volume control of aural section. Monitor is supplied complete with GM tube and probe. Dimensions: 6½" x 6½" x 10½". Weight: 8 pounds.



COUNTING RATE METER Model 1810, is a complete general purpose laboratory instrument, with provision for panel switch selection of *10 different counting rate ranges* and 8 *different response half-time factors*. For each position of the "Range" switch both range in counts per minute and the deviation in counts per minute may be *read directly* on the instrument panel. For each position of the "Response ½-time" switch both response half-time in seconds and the deviation multiplier for that particular response time may be *read directly* on the instrument panel. Thus it is possible to *select* absolute *optimum operating conditions* for any given circumstance. A zero meter check and a 7200 count per minute calibration are also provided. Unit includes regulated high voltage and low voltage supplies. Dimensions: 14½" x 9¾" x 10¾". Weight: 20 pounds.

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Famous Higinbotham Circuit
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Hermetically Sealed Transformers
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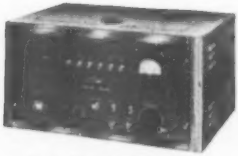

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Predetermined count type.
Automatically shuts off at 1-10-100-1000 counts.

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Meter scales change color and indication with rotation of range switch.
Built-in Regulated High Voltage Power Supply

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Direct reading in counts per second and counts per minute.
Four ranges of 5, 50, 500 and 5000 CPS

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An accessory for use with scalers—converts scaler to counting rate meter.
Four full scale ranges of 5, 50, 500 and 5000 CPS.

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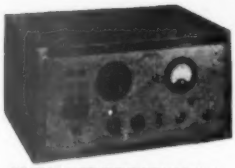
YOU CAN DEPEND ON EL-TRONICS INC. FOR INSTRUMENTS THAT COUNT!



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Alpha Proportional Count Rate Instrument operating from 110 V 60 CY. Built-in loudspeaker for audible monitoring. Meter to indicate high voltage applied to probe, and rate count.

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This little 4 pound meter has a range of 0 to 2500 MR/HR. Splash-proof design. Teflon range switch and chamber insulation assure a calibration accuracy ±10%. Battery life 1,000 hours.

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indirect. This conclusion is further supported by the results obtained with vitamin B_{12} in raw whole milk, which illustrates the protection phenomenon noted by Dale (*5*) and others.

Proctor and Goldblith (*6*) report that for raw whole milk the pasteurizing dose of 3-Mev electrons has been found to be 100,000 rep, and the sterilizing dose 500,000 rep. Results of the same magnitude have been found for milk irradiated with 3-Mev X-rays (*7*).

BIBLIOGRAPHY

1. J. G. Trump, R. J. Van de Graaff, *J. Applied Phys.* **19,** 599 (1948)
2. W. A. Winsten, E. Eigen, *J. Biol. Chem.* **181,** 109 (1949)
3. D. E. Lea, "Actions of Radiations on Living Cells," p. 74 (Macmillan Co., New York, N. Y., 1947)
4. B. E. Proctor, S. A. Goldblith, NUCLEONICS **5,** No. 3, 56 (1949)
5. W. M. Dale, *J. Physiol. London* **102,** 50 (1943)
6. B. E. Proctor, S. A. Goldblith, *Advances in Food Research* **3,** 166 (1951)
7. H. Fram, unpublished data (Dept. of Food Technology, MIT, 1947)

Microscope Operated Remotely For Radiation Studies

A remotely controlled metallographic microscope being installed at Knolls Atomic Power Laboratory, near Schenectady, N. Y., will be used to investigate the effects of radiation on materials. The instrument was designed and built by the General Electric Co. and the Instrument Division of the American Optical Co., Buffalo, N. Y.

The special microscope for examining the structure of highly radioactive specimens is located inside a concrete cell. Outside the cell are the eyepiece, the arc lamp used for illumination, a camera for recording results, and a remote-control panel. Two periscopes pierce the cell wall; one for illumination, the other for viewing. The offsets in the periscopes prevent radiation from reaching the outside of the cell.

Electric remote controls are used to operate the microscope. Ten objective lenses are mounted on a turret that can be rotated by remote control to obtain magnifications ranging from 1X to 1,000X. The objectives are adjusted so that it is not necessary to refocus when changing them.

Also operated by remote control are the coarse and fine adjustments for focusing the microscope, and all stage motions, including rotation and translation so that the specimen can be rotated under polarized light and scanned in two coordinate directions. The polarizer in the illumination system can be thrown in or out of position by remote control, and the analyzer that is built into the body of the microscope can be thrown in or out of operation and also can be rotated when it is in position.

In using the microscope, remotely controlled mechanical hands are used to place the radioactive sample on the microscope stage.

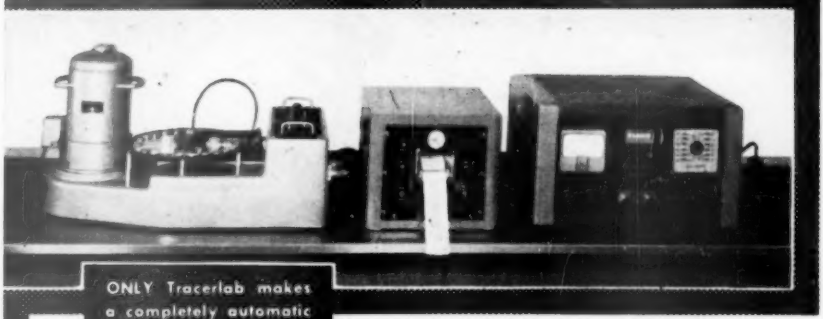
TECHNICAL BRIEFS

➢**Van de Graaff** electrostatic generator co-sponsored by AEC and the University of Texas, Austin, is nearing completion. Over one million volts have been produced in tests without vacuum tube and pressure vessel.

➢**Best insulation** for electrical wiring installed in high-neutron-flux area in a reactor is polyethylene. Ordinary nylon braid is satisfactory for periods of about one week and can be used for short experiments, according to J. C. Pigg in ORNL-865.

➢**Entire supply** of lead—domestic, imported and scrap—in the U. S. will be placed under regulation by the National Production Authority as soon as possible, probably January.

Fully Automatic Radioassays



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Tracerlab's Automatic Sample Changer allows laboratories making radioassays on a large number of samples to obtain data faster, more accurately, and with greater reproducibility. *Fully automatic* radioactivity measurements on as many as twenty-five samples can be made on this versatile unit without the attention of a technician. Results in terms of elapsed time are printed on a tape by the Tracergraph, which also prints a corresponding sample index number.

TRACERLAB MAKES OUTSTANDING END WINDOW GEIGER TUBES

In addition, half life measurements on short half life materials can be made, or, with the E-25 Automatic Absorber Attachment, energy spectrum data on a particular sample can be obtained with the unit automatically inserting absorbers of varying thickness over a fixed sample.

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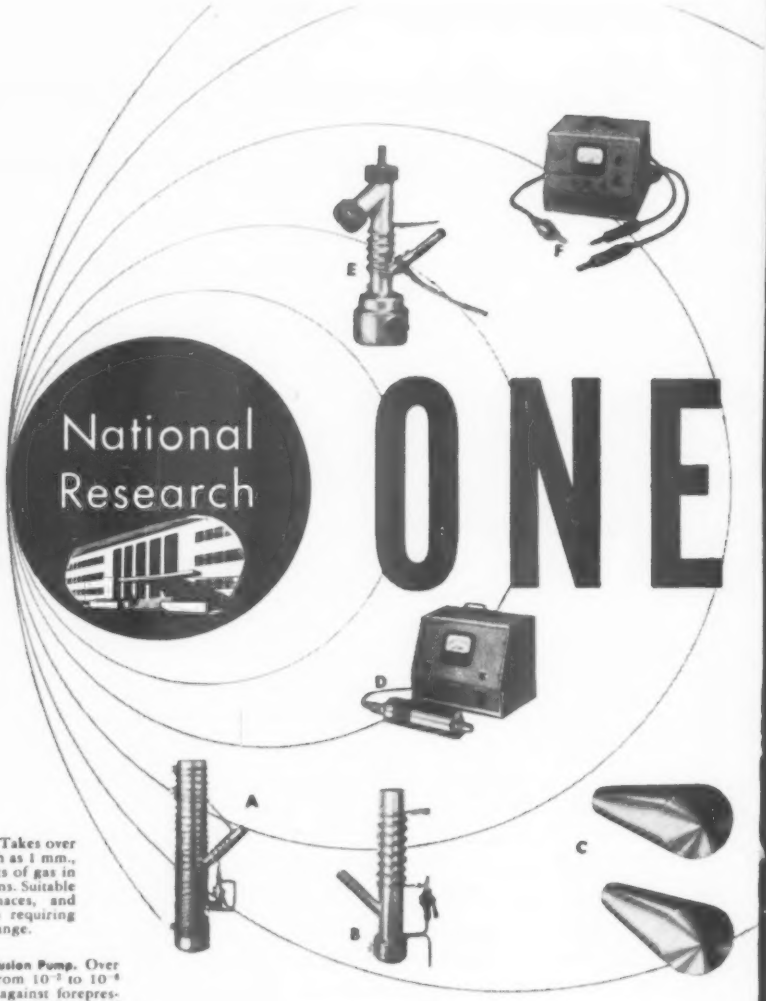

(A) 9-4 Booster Pump. Takes over at forepressures as high as 1 mm., handling large amounts of gas in range of 1 — 30 microns. Suitable for evaporators, furnaces, and other vacuum systems requiring high capacity in this range.

(B) H-2-P Purifying Diffusion Pump. Over 50 liters per second from 10^{-2} to 10^{-6} mm. range. Operates against forepressures as high as 0.300 mm. Blank-off 2×10^{-7} mm.

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(D) Alphatron® Vacuum Gauge. Accurate gauging from 10 mm. to 1 micron. A rugged metal ionization type instrument which can be adapted for recording, controlling, gas filling, and leak detection.

(E) 8-1 Booster Pump. A small pump designed for rotary exhaust equipment used in miniature and subminiature tube production. Useful where a small pump is required to quickly obtain pressures in the region of one micron.

(F) Type 710 Thermocouple-Ionization Gauge Control. One instrument for scientific and industrial vacuum gauging. Incorporates two thermocouple gauges (1 — 1000 microns) and one ionization gauge (10^{-2} mm. to 10^{-6} mm. Hg. range) in one control. Automatic input regulation and protective circuit.

(G) Standard Vacuum Furnace. A versatile packaged unit to melt, pour, heat treat, degas, sinter, and anneal under high vacuum or controlled atmospheres. Temperatures up to 2000° C.

(H) Vacuum Seals. For introducing motion, power, or connecting gauges.

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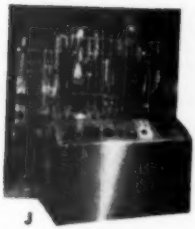
(K) Type 701 Thermocouple Gauge Control. A light, portable instrument for vacuum testing in range 1 — 1000 microns. Compact and rugged.



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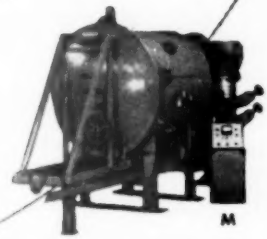

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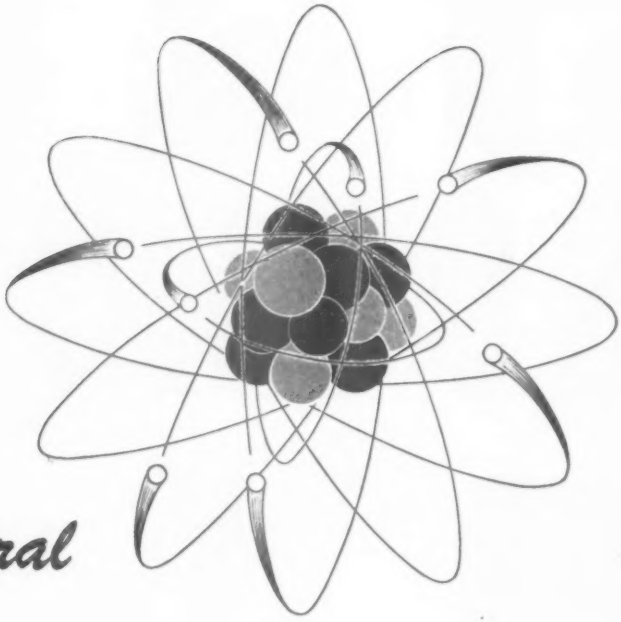

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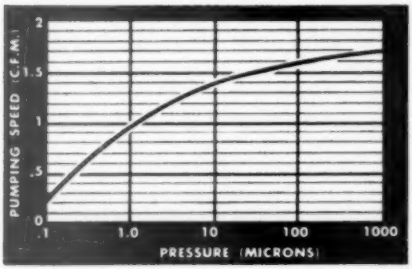

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was carried out, certain volumes in this series have assembled related work in a more satisfactory manner.

Although lack of uniformity for organic nomenclature of the polyfluorine compounds has been somewhat alleviated by an appendix which contains all probable and improbable names for a particular structure, annoyance and ambiguity can and still do cavort thru certain chapters. (*Caveat lector!*) It is unfortunate that the physical properties of fluorine and the many polychloropolyfluorocarbons as submitted by authors of individual chapters were not also assembled in an appendix. The reader's credulity is thoroughly tested by the different values for identical (?) compounds.

There appears to be a general lack of references to the literature, specifically to Manhattan Project reports; in some instances, serial numbers of patent applications are given in lieu of other references.

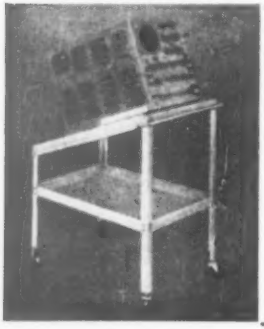
Nonuniformity also exists in the matter of credits and authorship. The inquisitive reader will be struck by the peculiar need for five or more authors for some chapters which, in footnotes, are purported to be abstracted from one doctoral dissertation. An omission is the lack of an author or personnel index to assist readers who may wish to locate investigations known to have been carried out by specific workers.

Editorial oversights include almost identical descriptions and photographs of the same fluorine cell in Chapters 6 and 25. A most intriguing problem for a freshman chemistry course is presented in the calculation of an empirical formula to be approximately $C_7H_xCl_2F_{10}$ (p. 289).

A number of chapters stand out in a particularly refreshing manner because of their excellence in coverage and presentation. *Industrial Handling of Fluorine* by R. Landau and R. Rosen describes the reaction of fluorine with construction materials and pipe dopes, physiological effects with therapy and safety methods, fluorine-proof fabrics, and waste disposal. Piping methods, storage, barricades, valves, and instrumentation with bellows transmitters are also considered. The tolerance level for HF is 3 ppm; although there is no accepted level for fluorine, there is no evidence that it should be lower than for HF.

Preparation of Fluorocarbons by Polymerization of Olefins by W. T. Miller describes the preparation of a suitable monomer, chlorotrifluoroethylene, its polymerizations, its condensation by cationic and anionic agents, and preparation of lower molecular weight com-

(Continued on page 90)



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pounds by thermal cracking of the higher polymers. The physical and chemical properties of sixty-five compounds are listed. References are made to project work in the bibliography of this chapter but report numbers are not included.

Vapor Phase Fluorination of Hydrocarbons by G. H. Cady, A. V. Grosse, L. L. Burger, and E. J. Barber describes some of the early efforts in the preparation of fluorocarbons; this chapter has the unique distinction as the only one with complete references to project reports. *Preparation of* n*-Polychloropolyfluoroheptene* by J. H. Babcock, W. S. Beanblossom, and B. H. Wojcik contains good descriptions of observations made during actual plan runs as to the effect of pertinent variables on the progress of the reaction.

—F. E. McKenna
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BOOKS RECEIVED

The Theory of Isotope Separation as Applied to the Large-Scale Production of U^{235} (Div. III, Vol. 1B, of National Nuclear Energy Series), by Karl Cohen, edited by George M. Murphy, McGraw-Hill Book Co., Inc., New York, 1951, xviii + 165 pages, **$2.** *(To be reviewed.)*

Semi-Conducting Materials, edited by H. K. Henisch, Academic Press Inc., New York, 1951, xv + 281 pages, $6.80. This is a collection of 27 papers presented at a conference held at the University of Reading under the auspices of the International Union of Pure and Applied Physics in cooperation with the Royal Society. A few papers touch on the irradiation of semiconductors with neutrons, charged particles, and X-rays, but the majority are concerned with phenomena associated with these materials and their properties.

Automatic Feedback Control, by William R. Ahrendt and John F. Taplin, McGraw-Hill Book Co., Inc., New York, 1951, xiv + 412 pages, **$7.50.** *(To be reviewed.)*

The Aurorae, by L. Harang, John Wiley & Sons, Inc., New York, 1951, x + 166 pages, $4.50. For specialists and students, this is Volume One of Wiley's new International Astrophysics Series.

Tensor Analysis—Theory and Applications, by I. S. Sokolnikoff, John Wiley & Sons, Inc., New York, 1951, ix + 335 pages, **$6.** This addition to the publisher's Applied Mathematics Series is graduate-level material. The subjects covered are linear vector spaces—matrices; tensor theory; geometry; analytical mechanics, relativistic mechanics; and mechanics of continuous media.

Astronomy of Stellar Energy and Decay, by Martin Johnson, Dover Publications, Inc., New York, 1951, 216 pages, $3.50. The answer to what is factual knowledge and exploratory theory in astrophysics today is provided in semi-technical fashion in this book written with the interests of the working physicist, undergraduate, and science teacher in mind.

OTHER LITERATURE

List of 25 Patents Released for Public Use by the AEC (Vol. I, No. 14, Oct. 24, 1951). *Issued by Chief, Patent Branch, Office of the General Counsel, U. S. Atomic Energy Commission, Washington 25, D. C.*

Industrial Uses of Radioactive Fission Products. Report of a techno-economic study recently made by the Stanford Research Institute. *Address Project 361, Stanford Research Institute, Stanford, Calif., for copies; $1.50 each.*

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ness intensification, by G. A. Morton and J. E. Ruedy, RCA Laboratories; and *A fluoroscopic screen intensifier for medical use*, by Russell H. Morgan and Ralph E. Sturn, Johns Hopkins Medical Institutions.

Other features of the conference include a demonstration lecture on television in medicine and biology and sessions on January 8 on the applications of circuit theory to medicine and electronic techniques to anesthesia.

IN BRIEF

➤**A $6.7-million contract** recently went to the Westinghouse Electric Corporation for equipment to carry electric power to the AEC's new Paducah, Ky., plant. Included in the contract are large numbers of 10 million-kva circuit breakers—largest ever constructed for use on 161-kv lines—and five 100,000-kva transformers.

➤***50 weather bureau stations** throughout the country cooperate to collect air, dust, and rainfall samples to be tested for radioactivity resulting from the A-weapons undergoing tests in Nevada. Analysis of the samples is made by Argonne, Brookhaven, the University of Rochester, Hanford, Oak Ridge, and the UCLA atomic energy project, as well as by the Health and Safety Laboratory of the AEC's New York Operations Office which serves as the central agency to coordinate the country-wide radiation-monitoring system. The purpose behind the project, the AEC says, is "to guide industries that might be affected by small increases in radiation levels."*

NUCLEAR NEWSMAKERS

Scientists recently appointed to key positions in the new National Science Foundation include: **Charles E. Sunderlin** as deputy director, **John Field** as head of the Biological Sciences Division, **Harry C. Kelly,** assistant director for the Division of Scientific Personnel and Education, **Paul E. Klopsteg,** assistant director for the Division of Physical, Mathematical, and Engineering Sciences, and **Lloyd M. Trefethen,** technical aide. Dr. Sunderlin, an organic chemist, is a former scientific director of the London Branch of the Office of Naval Research and U. S. Naval Academy faculty member. Dr. Field formerly directed the work of the Biology Branch of ONR; he is on leave as head of the Physiology Department of the Medical School of the University of California at Los Angeles. Dr. Kelly, a physicist, headed up the work of the Scientific Section of ONR in Chicago and before that was associated with the Radiation Laboratory at MIT. Dr. Klopsteg is on leave from Northwestern Institute of Technology, where he is professor of applied science and director of research. Dr. Trefethen is a former ONR technical aid.

Victor S. Hicks has joined Tracerlab, Inc., as chief physicist. Dr. Hicks was formerly associated with Ansco, Binghamton, N. Y., where he was in charge of the X-ray research laboratory.

R. H. Beaton has been appointed chief process engineer, a new position recently established in General Electric Co.'s engineering department at the Hanford Works. Dr. Beaton was formerly head of the separations technology division.

Robert R. Serber, one of the founders of the Los Alamos Scientific Laboratory and more recently a faculty member of the University of California, has been appointed professor of physics at Columbia University. He has also been named to the scientific staff of

Columbia's Nevis Cyclotron Laboratories at Irvington-on-Hudson, N. Y., and to Brookhaven National Laboratory as a consultant. Dr. Serber is well known for his pioneer work at the Universities of California and Illinois in connection with the theory of high-energy particle accelerators.

Harrison S. Brown has accepted appointment as professor of geochemistry at California Institute of Technology. He goes to Caltech from the University of Chicago where he was associated with the Institute for Nuclear Studies.

F. E. Kelsey, formerly associate professor of pharmacology at the University of Chicago, has joined the Nuclear Instrument & Chemical Corp. as director of radiochemistry.

Leland J. Haworth, director of Brookhaven National Laboratory, has been elected vice president of Associated Universities, Inc., the corporation which operates Brookhaven for the AEC. **George A. Brakeley,** vice president and treasurer of Princeton University, has been elected chairman of the AUI board of trustees, and **Lloyd V. Berkner** has been re-elected president. **Gerald F. Tape** has been named to the new post of deputy director of Brookhaven.

MEETINGS

American Association for the Advancement of Science—Philadelphia, Pa., Dec. 26–31

Symposium on Nucleation (sponsored by Division of Industrial and Engineering Chemistry of the American Chemical Society)—Northwestern Univ., Evanston, Ill., Dec. 27–28

American Physical Society—Berkeley, Calif, Dec. 27–29

Fourth Annual Conference on Electronic Instrumentation in Nucleonics and Medicine (sponsored by American Institute of Electrical Engineers)—Hotel Commodore, New York, Jan. 7–8

American Institute of Electrical Engineers, Winter General Meeting—Hotel Statler, New York, Jan. 21–25

Third Scintillation Counter Symposium—National Bureau of Standards, Washington, D. C., Jan. 29–30

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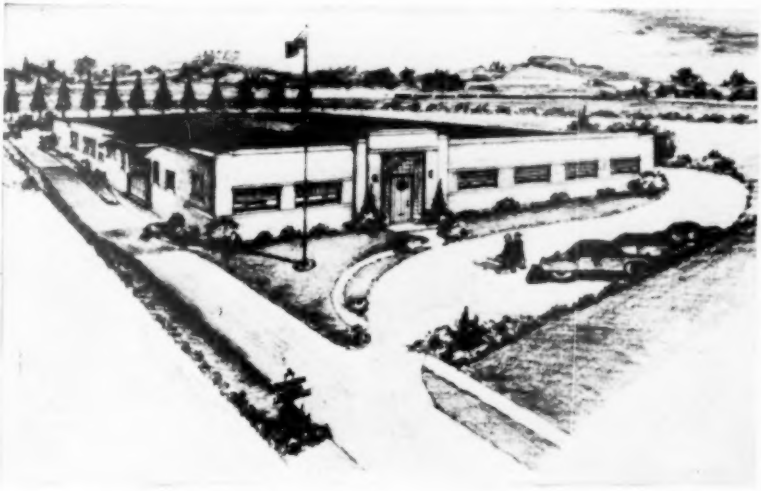

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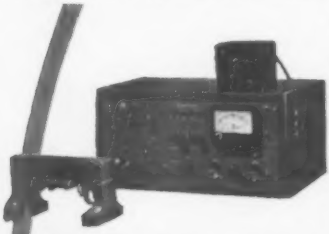

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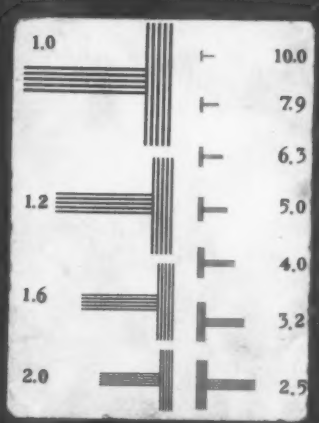

100 MILLIMETERS

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In microfilming, it is necessary to determine the reduction ratio and multiply the number of lines in the chart by this value to find the number of lines recorded by the film. As an aid in determining the reduction ratio, the line above is 100 millimeters in length. Measuring this line in the film image and dividing the length into 100 gives the reduction ratio. Example: the line is 20 mm. long in the film image, and 100/20 = 5.

Examine "T-shaped" line groupings in the film with microscope, and note the number adjacent to finest lines recorded sharply and distinctly. Multiply this number by the reduction factor to obtain resolving power in lines per millimeter. Example: 7.9 group of lines is clearly recorded while lines in the 10.0 group are not distinctly separated. Reduction ratio is 5, and 7.9 x 5 = 39.5 lines per millimeter recorded satisfactorily. 10.0 x 5 = 50 lines per millimeter which are not recorded satisfactorily. Under the particular conditions, maximum resolution is between 39.5 and 50 lines per millimeter.

Resolution, as measured on the film, is a test of the entire photographic system, including lens, exposure, processing, and other factors. These rarely utilize maximum resolution of the film. Vibrations during exposure, lack of critical focus, and exposures yielding very dense negatives are to be avoided.

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